Vol. 2 JANUARY, 1919 No. 1

Journal

—OF THE—

American Ceramic Society

A Monthly Journal devoted to the Arts and Sciences Related to the Silicate Industries.

COMMITTEE ON PUBLICATIONS:

GEORGE H. BROWN, Editor
Rutgers College, New Brunswick, N. J.

L. E. BARRINGER, *Chairman*,
General Electric Co., Schenectady, N. Y.

A. V. BLEININGER,
Bureau of Standards, Pittsburgh, Pa.

H. RIES,
Cornell University, Ithaca, N. Y.

E. W. TILLOTSON,
Mellon Institute, Pittsburgh, Pa.

CONTENTS

Subject *Page*

Editorials:

Coöperative Research 1
Local Sections 1
Ceramic Engineers 2

Original Papers and Discussions:

Refractory Materials as a Field for Research—Washburn 3
The Relative Action of Acids on Enamels—III—Poste 32
Compressive Strength of Cement-Lime Mortars—Kirkpatrick and Orange 44
Fusibility of Graphite Ash and Its Influence on the Refractoriness of Bond Clay—Booze 65
Clays for Use in Paper-Making—Roe 69

Acquisition of New Members during January, 1919 74

Published Monthly by the
AMERICAN CERAMIC SOCIETY

Publication Office
211 Church St., Easton, Pa.

Editorial Office
Rutgers College, New Brunswick, N. J.

SIX DOLLARS PER YEAR (Foreign Postage Additional) *SINGLE NUMBERS, SIXTY CENTS*

Entered as second-class matter, July 15, 1918, at the post office at Easton, Pa., under the Act of March 3, 1879.

Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized August 16, 1918.

Copyright, 1919, American Ceramic Society

AMERICAN CERAMIC SOCIETY.

OFFICERS, 1919–1920.

President: R. T. Stull, Bureau of Mines, Mining Experiment Sta., Columbus, O.
Vice-President: R. H. Minton, General Ceramics Co., Metuchen, New Jersey.
Treasurer: R. K. Hursh, University of Illinois, Urbana, Illinois.
Secretary: C. F. Binns, Alfred University, Alfred, New York.
Board of Trustees: The four above-named officers and E. T. Montgomery, R. D. Landrum, M. F. Beecher, G. H. Brown, and H. F. Staley.

OFFICERS OF LOCAL SECTIONS, 1919–1920.

Section.	*Chairman.*	*Secretary.*	*Councilor.*
Pittsburgh District	R. R. Hice	F. H. Riddle	F. W. Walker, Sr.
Northern Ohio	E. P. Poste	B. A. Rice	R. D. Landrum
St. Louis	C. W. Berry	G. R. Truman	D. T. Farnham
New England	A. A. Klein	G. J. Hudson	C. H. Kerr
Central Ohio	F. K. Pence	J. D. Whitmer	A. S. Watts
Chicago	W. D. Gates	F. B. Ortman	C. W. Parmelee
New York State	L. E. Barringer	J. B. Shaw	C. F. Binns

COMMITTEES, 1919–1920.

Committee on War Service.

A. V. Bleininger, *Vice-Chairman.*
R. C. Purdy.
L. E. Barringer.
A. S. Watts.
C. H. Kerr.
C. F. Binns.
E. W. Washburn.
R. T. Stull.
H. F. Staley.

Committee on Membership.

R. C. Purdy, *Chairman.*
R. D. Landrum.
R. L. Clare.
F. B. Ortman.
T. H. Sant.
R. D. Hatton.
F. H. Riddle.
F. K. Pence.
J. B. Shaw.

Committee on Papers and Programs.

R. H. Minton, *Chairman.*
John W. Sanders.
F. B. Ortman.
C. L. Sebring.
A. V. Bleininger.
C. H. Kerr.
M. W. Blair.
F. W. Walker, Sr.
R. C. Purdy.
C. F. Binns.

Committee on Coöperation.

C. H. Kerr, *Chairman.*
G. E. Barton.
W. E. Emley.
W. D. Gates.
Edward Hart.
F. R. Henry.
D. F. Riess.
Kenneth Seaver.
C. L. Sebring.
F. W. Walker, Sr.
A. F. Greaves-Walker.

Committee on Rules.

C. W. Parmelee, *Chairman.*
A. S. Watts.
S. G. Burt.
A. F. Greaves-Walker.
Ellis Lovejoy.

Committee on Standards.

M. F. Beecher, *Chairman.*
J. B. Shaw.
E. P. Poste.
E. E. F. Creighton.
C. W. Berry.
F. H. Riddle.
R. M. Howe.
Hewitt Wilson.
R. K. Hursh.
F. A. Kirkpatrick.
C. B. Harrop.
E. C. Hill.
M. C. Booze.

Committee on Local and Student Sections.

R. R. Hice, *Chairman.*
W. D. Gates.
M. E. Gregory.
F. K. Pence.
H. A. Wheeler.

Committee on Publications.

L. E. Barringer, *Chairman.*
G. H. Brown, *Editor.*
H. Ries.
E. W. Tillotson.
A. V. Bleininger.

PROFESSIONAL DIVISIONS.

Organized at the Pittsburgh meeting, Feb. 3–5, 1919.

Division.	*Chairman.*
Enamels	J. W. Sanders.
Terra Cotta	F. B. Ortman.
White Ware and Porcelain	C. L. Sebring.
Refractories	A. V. Bleininger.
Glass	C. H. Kerr.
Brick and Tile	M. W. Blair.
Wall and Floor Tile	F. W. Walker, Sr.

JOURNAL
OF THE
AMERICAN CERAMIC SOCIETY

A monthly journal devoted to the arts and sciences related to the silicate industries.

Vol. 2 **January, 1919** **No. 1**

EDITORIALS.

COÖPERATIVE RESEARCH.

The comprehensive plan for the organization of a refractories research association, as outlined in this number of the JOURNAL by Dr. Washburn, merits careful consideration and thorough discussion. The fact that similar research organizations have been fostered by groups of manufacturers in other industries and have been found worth-while, both in the advancement of technique and from the standpoint of a financial investment, is a strong argument for associations of this kind.

It would appear that the ceramic industry, comprised as it is for the most part of small units, offers a promising field for research associations, not only as related to refractories, but in the several branches of the industry. The stimulated interest on the part of our manufacturers in technical advancement is evidenced by the increased support which they are lending to the American Ceramic Society and related organizations and by the unusual demand for men with technical ceramic training. The old secretiveness and rule of thumb methods are gradually giving place to coöperation and exchange of ideas and experiences. The support which the Refractories Manufacturers' Association is giving to the maintenance of a research laboratory of its own is a step in the right direction. An avenue for the further advancement of this and other branches of the industry will undoubtedly be found through the recently organized Professional Divisions of the Society.

Some of the difficulties to be encountered in launching organizations of this kind may appear insuperable at the start but a co-

ordination of the activities of our present research laboratories would be a long step toward the consummation of the greater and ideal research organizations.

LOCAL SECTIONS.

The following telegram, recently received by the Chairman of the Membership Committee, is indicative of the interest taken in the Society by workers in the silicate industry in all parts of our country:

Los Angeles, Calif., February 12, 1919.

There are about a dozen good men in town and more in the vicinity who should become members of the American Ceramic Society. Please send descriptive literature, application blanks and full information at once. There is a possibility also of a Western Section in which affiliated lines would coöperate. Send complete data. P. A. B.

The Chairman reports the same interest shown from Toronto, Canada. Such interest on the part of individuals bespeaks the organization of more Local Sections, stronger Professional Divisions and a larger membership than even the most optimistic of us have visioned.

CERAMIC ENGINEERS.

Although with the curtailment of war activities, there appears to be no dearth of chemists and engineers in most lines, the demand for men with technical ceramic training appears to be as acute as during the last year of the war. This is significant, in view of the present period of reconstruction and consequent marking time in the industry. The comparatively small number of men to be graduated from the ceramic departments of our colleges and universities at the close of the present school year will not fill the vacancies, and the demand will be felt for some time to come.

In order that an adequate and continuous flow of technically trained men be available for the future requirements of the industry, the enrollment in our ceramic schools should be increased. A normal increase is to be expected but it is to be hoped that some means will be found to enlist the interest of a greater number of prospective college students in the possibilities for advancement in the silicate industries.

ORIGINAL PAPERS AND DISCUSSIONS.

REFRACTORY MATERIALS AS A FIELD FOR RESEARCH.

A Survey of the Scientific Aspects of the Subject.[1]

By Edward W. Washburn, Chairman, Committee on Ceramic Chemistry, National Research Council.

1. **Definition of the Term Refractory Material.**—For the purpose of defining an homogenous class of materials for systematic investigation, the term "refractory material" *will be here understood* to signify any non-metallic material capable of withstanding elevated temperatures, without destruction or deterioration (by fusion, sublimation, chemical decomposition or physico-chemical transformations) so rapidly as to preclude its use in the construction of vessels, linings, furnace walls, flues, etc., subjected to high temperatures. Although resistance to high temperatures is the primary and distinguishing characteristic demanded of refractory materials as a class, almost every refractory employed in modern industry must also exhibit, while at a high temperature, an adequate resistance toward one or more of the following destructive agents: (1) pressure or load; (2) mechanical vibration; (3) frequent, rapid and unequal heating or cooling, or any one or more of these; (4) the stresses set up by expansion or contraction of other parts of the furnace or vessel of which the refractory material is a component part; (5) mechanical abrasion by ashes, cinders, etc., or by the furnace charge itself; (6) the chemical action of atmospheric and furnace gases; (7) the slagging action of the furnace charge or of materials given off by it; and (8) the

[1] This report was drafted under the auspices of the Section of Industrial Research of the National Research Council, as a preliminary step in the consideration of the nature of the problems involved in research in this field and of the possibilities of attacking them by concerted action.

chemical action of any other furnace parts such, for example, as the electrodes or the heating element in an electric furnace; and in certain special cases the refractory must (9) while at high temperature (*a*) remain a good electrical insulator, or (*b*) become an electrical conductor; or (10) (*a*) remain a good thermal insulator, or (*b*) become to a given degree a thermal conductor.

2. The Importance of the Subject.[1]—Every industrial plant which employs high temperatures in any part of its work has a more or less acute problem of refractory materials to deal with. The refractory materials employed may vary all the way from the ordinary fire bricks (such as are employed in the boiler settings of the power plant) to highly specialized materials designed to withstand one or more of the special destructive agents mentioned above. Railway locomotives and the power plants of ships can be operated with the highest efficiency only when properly designed refractory materials are used in their construction.

Practically all of the metallurgical industries, both those which have to do with the extraction of metals from ores as well as those engaged in working the various metals or preparing alloys, have especially trying and difficult refractory problems to meet. An important part is also played by refractory materials in the manufacture of electric furnace products (such as abrasive materials, graphite, carbide, nitrogen products from the air, and a variety of other chemical products); of glass and quartz articles; of lime, cement, potash, fuel gas, ammonia, coke, and many of the pigments; and of course of all ceramic products.

As a field for industrial research, the subject of refractory materials is, therefore, fundamental in character and widespread in its practical applications. The present trend of many industries in the direction of using increasingly high temperatures[2] in their operations is a further indication of the growing importance of

[1] See also Geo. A. Balz, "Why Refractories Are a World Necessity," *Brick and Clay Record*, **48**, 741 (1916).

[2] "It will be recognized by all who have studied the matter closely that the future industrial success of any country will largely depend upon the extent to which it develops high temperature processes." Cantor Lecture by C. R. Darling, before the Royal Society of Arts, London, February, 1918.

a thorough and systematic scientific investigation of the various problems connected with the preparation and use of refractory materials.

3. **Conservation of Fuel.**—In a high temperature furnace or kiln, where the internal temperature required is higher than the refractory lining will withstand, it is customary to protect this lining by artificial cooling either by means of air or water. Such artificial cooling naturally results in a great waste of heat and in a corresponding greater consumption of fuel. The ideal arrangement would be to cover the outside of the furnace with a good thermal insulator so as to retain this heat in the furnace, but in many cases under present conditions such an insulation would result in the rapid destruction of the refractory lining, owing to the fact that this lining would soon attain the temperature of the inside of the furnace. It is obvious that the development of refractory materials which would permit the thermal insulation of industrial furnaces would result in an enormous fuel saving since the wastage resulting from present methods is one of the large elements in the total fuel consumption of industrial furnaces. Perfect adaptation of the refractory to furnace conditions (temperature, pressure, chemical action, mechanical abrasion, etc.) is one of the big problems whose successful solution would constitute a great contribution to the fuel conservation movement.

4. **Annual Production and Consumption of Refractory Materials in the United States.**—Complete statistics on the annual production of refractory materials and products in the United States do not seem to be available in public records but from the data at hand the value of the annual production of such materials may be safely estimated as greater than (60) sixty million dollars.

The following statistical data on the subject have been recently compiled at the writer's request from the records of the United States Geological Survey:

Bauxite refractories.—In 1917 the bauxite used for the manufacture of refractory wares was about 12,000 tons. Approximately three (3) million bricks $2^1/_2 \times 4^1/_2 \times 9$ inches were sold, valued from $50 to $380 per thousand. In 1917 the bauxite used in the manufacture of refractory wares was over 2,500 tons,

but exact figures are not available, nor is information as to the quantity or value of the products made.

Refractories manufactured from quartz, chert, silica, fused silica, etc.—Except as elsewhere noted concerning silica brick, the Geological Survey has no record of the manufacture or production statistics of refractory wares made of these materials. Only the total output of silica in various raw forms is known, and this is not separated or classified according to uses.

Refractories manufactured from ganister.—There is no available record of the refractory wares and materials made of ganister. The Survey's record of ganister production—that is, sales of quarry products—is as follows:

PRODUCTION 1913–1917.

	Short tons.	Value.
1913	.....	$ 376,775
1914	.....	288,244
1915	573,304	336,267
1916	859,956	529,805
1917	1,001,630	1,117,558

Mica schist for furnace linings.—The following data concerning the production of mica schist for furnace linings are available:

PRODUCTION 1913–1917.

	Short tons.	Value.
1913	....	$45,102
1914	....	54,567
1915	....	24,625
1916	33,236	47,304
1917	39,975	85,986

Magnesite refractories.—Statistics of the quantity and value of magnesite produced and sold in the United States are available, but no information is at hand as to the proportions of this material which enter into refractories, magnesium chloride, magnesia, alba, manufacture of paper and other products. The Geological Survey assumes that the only source of information as to the quantity of refractory brick and shapes made from magnesite in the United States would be by a canvass of the manufacturers.

Dolomite refractories.—The Geological Survey has only the following statistical information:

ESTIMATE OF DOLOMITE AND EQUIVALENT IN "DEAD BURNED" LIME, PRODUCED FOR REFRACTORY PURPOSES 1914–1917.

	Dead burned. Short tons.	Unburned. Short tons.
1914	13,053	26,058
1915	50,223	100,446
1916	136,240	267,446
1917	176,876	234,720

Chromite refractories.—There is no available information on the quantity and value of chromite used in the manufacture of refractory wares, or on the value of the refractories manufactured, other than statistical data showing that 4364 long tons of chromite in the form of refractories were consumed during the first half of 1918 and that 1959 long tons were similarly consumed during July, 1918.

Graphite refractories.—So far as known to the U. S. Geological Survey, there are no statistics showing quantity of molded graphite articles, such as graphite crucibles, anywhere available for the years asked for, or for that matter, for any periods.

Quartz-glass and fused silica refractories.—No available data.

Zirconia refractories.—Data concerning the total annual production of zirconium minerals are contained in the Annual Mineral Resources Reports.

Rare earth refractories.—The following information is taken from the report on the gas-mantle industry now in the files of the United States Tariff Commission:

PRODUCTION AND IMPORTATION OF THORIUM NITRATE IN THE UNITED STATES, 1913–1917.

Year.	Quantity produced. (Pounds.)	Quantity imported. (Pounds.)
1913	Information confidential cannot be published.	112,105
1914		144,413
1915		78,516
1916		22,261
1917		1,877

Clay Refractories.—The following statistics on the value of clay refractories manufactured in the United States for the years 1913 to 1916 have been compiled by the United States Geological Survey:

Product.	1913.	1914.	1915.	1916.
Fire brick, including refractory block or tile, boiler and locomotive tile, tank blocks and similar refractory products..	$16,811,316	$13,476,022	$15,800,062	$25,155,519
Other fire brick, including some special shapes, etc.....	134,635	115,144	121,747	311,052
Silica brick, including clay-bond and lime-bond brick.....	3,815,806	2,951,525	3,039,869	5,650,610
Zinc retorts.....	(c)	576,655	823,545	1,553,691
Zinc condensers.....	(d)	176,591	260,436	512,453
Glass melting pots and other glass-house refractories (Special effort to collect statistics of these products from the consumer manufacturing for his own use was not made prior to 1915.....	568,603	498,096	719,889	1,989,754
Gas retorts.....	65,846	41,372	23,835	35,821
Charcoal furnaces (portable).....	37,217	36,243	32,865	27,280
Muffles, scorifiers, assay supplies and crucibles (other crucibles are included with chemical porcelain and chemical stoneware).....	63,869	67,367	98,105	364,563

Saggers (prior to 1917 statistics for saggers were not collected from the sagger consumer manufacturing for his own use)	(e)	(e)	(e)	34,476
Chemical porcelain and chemical stoneware	(f) 224,894	(f) 246,918	(f) 620,401	1,054,061
Potters' supplies (pins, stilts, and spurs)	125,987	130,740	126,780	188,643
Mantle rings and special ware for gas lighting and heating, including magnesia ware and refractory porcelain for electric ranges and heaters (including a small valuation for pins and stilts)	(e)	(e)	172,261	220,849
Undistributed refractory products	364,519	329,423	22,288	.....
Total	$22,212,692	$18,646,096	$21,862,083	$37,098,772

(c) Reported by one producer only for 1913, and included with "Undistributed refractory products"—statistics for zinc retorts were not collected prior to 1914.

(d) Reported by one producer only for 1913 and included under Miscellaneous—statistics for zinc condensers were not collected prior to 1914.

(e) Reported by less than three producers—included in "Undistributed refractory products."

(f) Chemical porcelain and chemical stoneware, not separately classified prior to 1916, were probably partly reported under Stoneware and *Yellow* and Rockingham ware in 1913, 1914, and 1915.

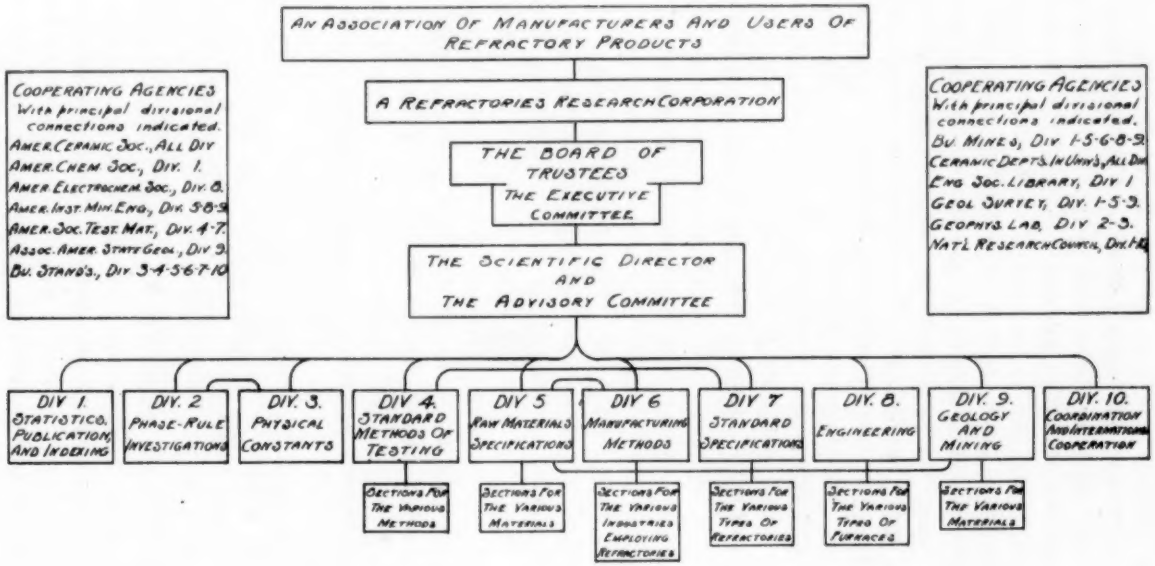
5. An Organization for the Prosecution of Research in Refractory Materials.—In outlining and describing the various aspects of the subject of refractory materials as a field for research, we shall first create, for convenience of presentation, a hypothetical organization, which we shall assume proposes to engage in a complete and systematic study of *all problems* connected with the nature, preparation, properties, and industrial application of refractory materials. It will be understood, therefore, that the particular organization described below is a purely fictitious one created on paper, merely as a convenient machine for setting forth in systematic fashion the various scientific aspects presented by the subject of refractory materials as a field of research. It is not suggested that this organization, created here as a convenient means of classifying the different aspects of our problem, would be the most suitable type of organization for actually undertaking to carry out research in this field, since in constructing an actual working organization various practical questions would have to be considered which do not enter into a plan of organization designed merely to display the different scientific aspects of the problem. It is not the writer's intention to propose at this time any particular type of working organization since the formation of such an organization would require the combined labors of a group of experts familiar with all of the practical questions involved. It is hoped, however, that the type of organization employed here, for the purpose indicated, will, in so far as it sets forth in a systematic manner all of the various scientific aspects of the subject, be convenient as a starting point in planning some practical working organization for undertaking the solution of the many important questions which our subject presents.

With this explanation therefore we shall assume that our hypothetical research association or corporation finds it convenient to organize itself into divisions for handling the different parts of its work. These divisions might be somewhat as follows:

A. The Board of Trustees and the Executive Committee.
   (1) The Division of Statistics, Publication and Indexing.
   (2) The Division of Phase-Rule Investigations.
   (3) The Division of Physical, Chemical, and Ceramic Properties of Raw Materials and Manufactured Products.

ORGANIZATION OF A REFRACTORIES RESEARCH ASSOCIATION

Designed to display the various subdivisions of the field and their interrelations.
Not proposed as the best immediate form for a working organization.


An Association Of Manufacturers And Users Of Refractory Products
A Refractories Research Corporation
The Board Of Trustees
The Executive Committee
The Scientific Director And The Advisory Committee
Cooperating Agencies
With principal divisional connections indicated.
Amer. Ceramic Soc., All Div
Amer. Chem. Soc., Div. 1.
Amer. Electrochem. Soc., Div. 8.
Amer. Inst. Min. Eng., Div. 5-8-9
Amer. Soc. Test. Mat., Div. 4-7
Assoc. Amer. State Geol., Div 9.
Bu. Stand's., Div 3-4-5-6-7-10
Cooperating Agencies
With principal divisional connections indicated.
Bu. Mines, Div 1-5-6-8-9.
Ceramic Depts. In Univ's, All Div.
Eng. Soc. Library, Div 1
Geol. Survey, Div. 1-5-9.
Geophys. Lab. Div 2-3.
Nat'l. Research Council, Div. 1-2
Div 1. Statistico. Publication, And Indexing
Div. 2 Phase-Rule Investigations
Div. 3. Physical Constants
Div 4. Standard Methods Of Testing
Div 5 Raw Materials Specifications
Div 6 Manufacturing Methods
Div 7 Standard Specifications
Div. 8. Engineering
Div. 9. Geology And Mining
Div. 10. Coordination And International Cooperation
Sections For The Various Methods
Sections For The Various Materials
Sections For The Various Industries Employing Refractories
Sections For The Various Types Of Refractories
Sections For The Various Types Of Furnaces
Sections For The Various Materials

(4) The Division of Standard Methods for Testing Refractory Products.
(5) The Division of Raw Materials Specifications.
(6) The Division of Manufacturing Methods.
(7) The Division of Standard Specifications for Refractory Products.
(8) The Engineering Division.
(9) The Division of Geology and Mining.
(10) The Division of Coördination and International Cooperation.

6. The Board of Trustees and the Executive Committee.—The Board of Trustees would be charged with the raising and expenditure of all funds and would exercise general supervision over the financial affairs of the Association. It would elect the Scientific Director and on his nomination appoint the chiefs of all Divisions.

The Executive Committee of the Board would be empowered to act for the Board in the intervals between Board meetings. After receiving the recommendations of the Advisory Committee, it would prepare the annual budget for presentation to the Board of Trustees and would also prepare the program of business for each meeting of the Board.

7. The Scientific Director and the Advisory Committee.—The Scientific Director would exercise general supervision over all of the research work of the Association. He would make all nominations for heads of Divisions and would transmit to the Executive Committee, with his recommendations, all nominations for appointment to positions on the research staff. For a time at least, he might also act as the head of one of the Divisions since he would presumably be specially qualified as an expert in at least one of the principal lines of work of the Association.

The chiefs of all Divisions, together with possibly one or two additional members of national reputation as experts in industrial research, would constitute an Advisory Committee to the Scientific Director. This Committee would be charged with the preparation of the annual program of research and the necessary budget

for accomplishing it. This program and budget would be transmitted by the Director to the Executive Committee of the Board of Trustees, which body would exercise the final judgment concerning the program and budget.

8. Division 1. Statistics, Publication and Indexing.—The duties of this Division would be as follows:

(1) The preparation of an exhaustive classified bibliography of the extensive and widely scattered literature on the subject of refractory materials and all matters relating thereto. This bibliography should be indexed and cross-indexed to the fullest degree so that the literature might be utilized to the best possible advantage. After publication this bibliography should be kept up to date by means of annual or semi-annual supplements which might be combined decennially into new editions.

(2) By coöperation with the American Chemical Society, the work of securing and publishing abstracts of all papers dealing with any aspect of the subject of refractory materials should be promoted and improvements secured in the abstracting and in the arrangement and cross-indexing of the abstracts in the pages of *Chemical Abstracts*.

(3) To supplement the above bibliographic material, the Division might arrange with competent experts for the preparation and publication, from time to time, of critical digests in the form of monographs on selected topics. Each of these monographs should be an exhaustive, critical presentation and discussion of all the essential known facts concerning the subject matter and should contain a complete set of tables of numerical data and a complete bibliography. In this way, it would be possible to build up gradually a library of authoritative and trustworthy works of reference dealing with all the various aspects of refractory materials and their uses.

Each important refractory material (silica, magnesite, kaolin, alumina, etc.) might become the subject of such a monograph as might also the practice and requirements of each type of industry employing refractories. Not the least value of such a set of monographs would be its revelation of the relatively small amount of really reliable scientific data available on the subject

of certain refractories and the enormous amount of work which still remains to be accomplished. The preparation of such a monograph should precede the undertaking, on any extensive scale, of a program of research on any given topic.

(4) The biennial publication of a handbook of tables of physical, chemical and ceramic constants relating to refractory materials and products as well as standard methods for testing and examination would be valuable. In the preparation of such a handbook, this Division would work in coöperation with Division 3.

(5) Either through the medium of a journal of its own, or preferably through arrangements with one or more established journals, the Division should provide for the publication of all investigations carried out under the auspices of the Association, in all cases where such publication has been approved by the Board of Trustees.

(6) By coöperation with the appropriate governmental agencies, such as the Bureau of the Census and the U. S. Geological Survey, the Division should endeavor to secure improvements in the collection of statistics relating to refractory raw materials and manufactured products, to the end that all valuable statistical information on this subject should be properly collected and classified.

(7) This Division might also become responsible for the more general diffusion of accurate information concerning the manufacture and use of refractory materials and to this end might inaugurate a publicity program for educational purposes.

9. Division 2. Phase-Rule Investigations.—This Division would have general charge of the initiation, promotion, and direction of the most fundamental as well as the most difficult and expensive scientific studies which are required in building up our scientific knowledge of the refractory materials themselves.

As regards the common characteristic possessed by all refractory materials, that of resistance to high temperature, the initial problem presented for experimental investigation is to a large degree a problem in physical chemistry involving as its most important feature the application of the Phase-Rule and the laws of solutions. Thus, in accordance with the known laws of

physical chemistry, the effect of the presence of impurities in a refractory material is always to decrease the refractory power,[1] except when the proportion of the impurity is so large as to cause the composition of the mixture to coincide with a maximum point in the phase-rule diagram for the system, under which conditions the effect of the "impurity" may be either a decrease, an increase, or no change at all in the refractory power, depending upon the materials involved. According to the same laws, it is also in nearly all cases true that the larger the number of materials employed in the manufacture of a refractory product, the lower will be its refractory power. A great many of the patents issued for refractory materials cover products whose manufacture violates all of the principles mentioned above. These principles are also violated in the rather widespread idea that, as a general rule, the refractory power of a given material can be increased by mixing with it a second, *more refractory material*. Indeed the various formulas, which are given in text books and treatises on ceramic subjects, for calculating the refractory power (*i. e.*, softening point) of a mixture from its composition and the melting points of its components, seem to have been formulated without regard to established physico-chemical laws.

An illustrative example.—In order to illustrate the importance and the fundamental character of the physico-chemical relations displayed by the phase-rule diagram, in the solution of problems connected with the manufacture and use of refractories, a brief consideration of such a diagram for the system, magnesia-alumina, will be given here. In other words, given the two substances magnesia, MgO, and alumina, Al_2O_3, what are the possibilities, as displayed by the phase-rule diagram, of manufacturing refractory products from these two materials? The phase-rule diagram for this system is shown in Figure 1.[2] In this figure temperatures are indicated vertically and compositions, expressed in weight per cent, horizontally.

Both magnesia and alumina are separately employed in the industries as refractory materials. Alumina, however, at present

[1] For a statement of the factors which determine the fusibility of a material, see Washburn, *Trans. Am. Ceram. Soc.*, **19**, 195 (1917).

[2] See Rankin and Merwin, *J. Am. Chem. Soc.*, **38**, 571 (1916).

market prices is considerably cheaper per pound than magnesia. Either substance when employed alone presents the difficulty of finding a suitable bonding material to use when shaping into the desired form, since any foreign bonding material which remains in the product after firing results in a lowering of the refractory power, while a bonding material which burns out during

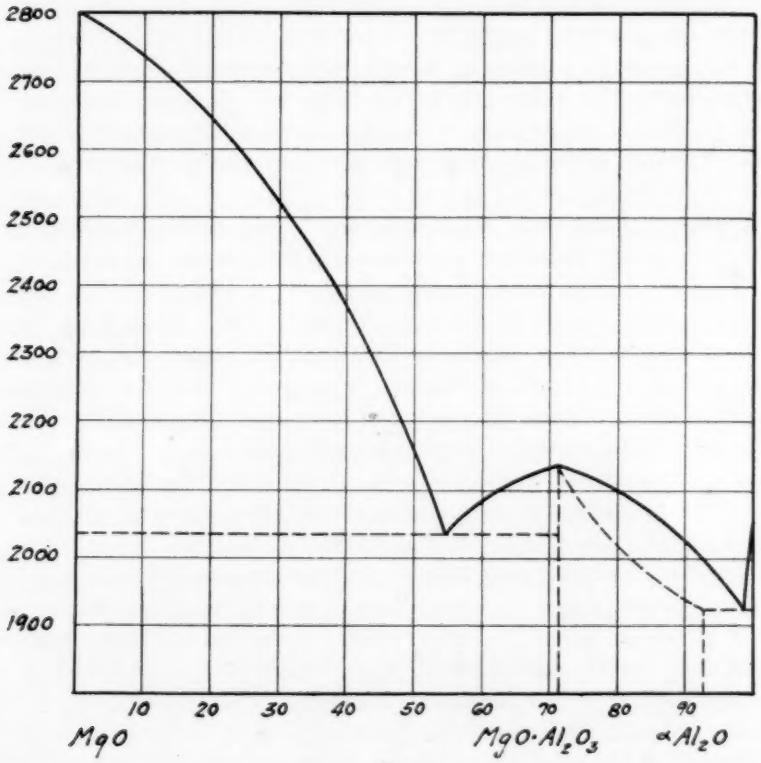


FIG. 1.

the firing leaves a loose structure with insufficient mechanical strength for many purposes.

The diagram shows that pure magnesia will not liquefy until a temperature of 2800° C is attained. In other words, as far as its mere resistance toward softening at high temperatures is concerned, magnesia is one of the most refractory substances which we

have. Although no liquefaction occurs below 2800° C, considerable deterioration occurs at much lower temperatures owing to crumbling, spalling, and sublimation, the volatility of the magnesia being so high that at high temperatures the magnesia vapors from a furnace lining will fill the whole interior of the furnace and condense upon everything contained therein. This characteristic makes it undesirable to use magnesia as a refractory for many purposes.

In order to increase the mechanical strength of a refractory body, both in the green state and after firing, it is frequently customary to mix with the principal constituent a small amount of a second constituent to act as a bond. For example, let us suppose that small amounts of alumina were mixed with magnesia for this purpose. The problem then presents itself as to the magnitude of the effect of such admixtures upon the refractory power of the magnesia. The answer to this question can be obtained from the phase-rule diagram. The curve in Fig. 1 shows that if any quantity of alumina, no matter how small and not exceeding 70 per cent, be mixed with the magnesia, the liquefaction temperature, that is the temperature at which liquefaction will *begin*, drops at once from 2800° to 2030°. In other words, alumina, present as an impurity or added for bonding purposes to magnesia, always decreases the initial liquefaction temperature by 770°.

This initial liquefaction temperature is known as the "eutectic temperature," and the first portions of liquid which appear when this temperature is reached will not have the composition of the original body, but instead will have what is known as the eutectic composition, that is, the composition corresponding to the eutectic point, which for the case under consideration is shown by the diagram to be 55 per cent of alumina and 45 per cent of magnesia. The maximum amount of this liquid which can be formed by heating the refractory body to any given temperature can also be readily calculated from the diagram. The resultant weakening of the mechanical strength of the refractory body depends of course upon the amount of this liquid which is formed. A small quantity of liquid might be held in the pores of the body without decreasing very greatly its mechanical strength, but as the amount

of the liquid increases the strength of the body continually decreases until finally a cone made of the material is no longer able to stand up under its own weight, owing to the fluidity produced by the presence of the eutectic liquid in its pores.

Turning now to alumina, we notice from the diagram that a refractory body made of pure alumina will show no liquefaction whatever until a temperature of 2050° is reached, while the admixture of any quantity of magnesia not exceeding 30 per cent by weight with the alumina will give a body which begins to liquefy at 1925°, which is the eutectic point on the right of the diagram. It is evident that alumina as an impurity in magnesia produces a much greater lowering in the initial liquefaction temperature than does magnesia as an impurity in alumina.

Whenever a phase-rule diagram exhibits a maximum point, it always means that a chemical compound is formed between the two components, the melting point of this compound being the temperature corresponding to the maximum point and the composition of the compound being the abscissa of this point. Thus the diagram in Fig. 1 tells us that a chemical compound between magnesia and alumina containing 28 per cent of magnesia and 72 per cent of alumina and hence having the formula $Al_2O_3 \cdot MgO$ is formed and that this compound has a melting point of 2135°. If therefore we proceed to manufacture a refractory body by mixing together alumina and magnesia in the molal ratio 1 to 1 (*i. e.*, 28 per cent MgO and 72 per cent Al_2O_3 by weight), we can obtain a product which can be employed as a refractory at any temperature up to 2135° without the occurrence of any liquefaction. This magnesium aluminate is thus a somewhat better refractory than alumina alone, since it will stand a temperature 85° higher than pure alumina will. The diagram also shows that small errors in the composition of the body would not produce very serious results upon its refractory power since an excess of alumina lowers the liquefaction temperature only 210° and an excess of magnesia only 105°.

In addition to the increase in refractory power which can be obtained by adding to alumina enough magnesia to combine completely with it, certain other advantages are secured at the same time. We have mentioned above the difficulty of securing

a bond when manufacturing a refractory out of a single material; in fact, to manufacture a refractory of high mechanical strength out of pure alumina would require either long firing or a firing temperature close to the melting point, that is, a firing temperature of about 2000° which is scarcely practicable on an industrial scale, except with the aid of an electric furnace. By mixing together magnesia and alumina in the molal ratio of 1 to 1 and firing the resultant body, the compound, magnesium aluminate, will form, even at temperatures considerably below its melting point. The formation of this compound, which probably occurs through the gaseous phase owing to the mutual vaporization of the constituents in the pores of the body, usually results in a mass of small interlacing crystals and consequently gives a product of increased mechanical strength and toughness. The formation of this compound is accompanied by a large shrinkage during burning, and a consequent increase in density thus making it desirable to pre-calcine and grind part of the body mixture before shaping into the desired form.

The formation of such a compound between the two materials may also be expected to decrease greatly the volatility of both materials; to increase their resistance toward many chemical agencies and in some cases toward mechanical abrasion.

Still greater mechanical strength, as well as a diminished porosity and greater resistance toward mechanical abrasion than that which is produced by the chemical combination, referred to above, can of course be secured by adding to the body a material for the purpose of producing vitrification; but the increased strength and resistance obtained in this way can usually be secured only with the sacrifice of some of the refractory power. While it is not necessarily impossible to produce vitrification without loss of refractory power, extremely high firing temperatures would usually be required to obtain such a result.

The above conclusions may be summed up as follows: Any refractory body manufactured from alumina and magnesia will begin to liquefy at 1925° if it contains less than 71 per cent of alumina, and at 2030° if it contains more than 71 per cent of alumina. But a body having exactly the composition, 71 per cent alumina, will show no liquefaction whatever until a tem-

perature of 2135° is reached. The amount and composition of the liquid which is formed by heating a body composed of magnesia and alumina in *any given* proportions to *any given* temperature can be exactly calculated from the phase-rule diagram. Owing to the formation of a chemical compound between the constituents, decreased volatility with increased mechanical strength and resistance to abrasion and chemical action may be looked for. Numerous other examples illustrating the value of phase-rule diagrams in solving problems connected with the preparation and behavior of refractory materials might be cited.[1]

Among the substances which might properly be included in a comprehensive phase-rule investigation of refractory materials are the following: carbon, silica; the oxides of calcium, strontium, barium, magnesium, and beryllium; the oxides of alumina, iron, chromium and molybdenum; the oxides of titanium and zirconium; various rare earth oxides; and certain nitrides and carbides—such as boron nitride and silicon carbide. In addition to these substances, the oxides of the alkali metals should also be included because of their common occurrence as impurities in refractory raw materials and their powerful fluxing action, made use of in producing vitrification.

The total number of different systems which could be prepared by the combination of even 20 different components, up to and including four-component systems, is at least 6195, so that evidently the task of making anything like an exhaustive investigation covering all of the above materials would be enormous. It is evident therefore that a selection of the systems to be studied would be necessary, based upon the relative importance of these systems for practical purposes.

Most of the experimental work which has been required in order to complete the study of the few systems which have thus far been thoroughly investigated has been carried out in the Geophysical Laboratory of the Carnegie Institution of Washington. The phase-rule diagrams for the following systems have thus far been wholly or partially completed:

[1] See Sosman, *J. Ind. Eng. Chem.*, **8**, 985 (1916); *Trans. Far. Soc.*, **12** (1917).

1. One-component systems: silica, alumina, magnesia, lime, carbon.

2. Two-component systems: silica–alumina, silica–magnesia, silica–lime, ferric oxide–lime, alumina–lime, alumina–magnesia, hematite–magnetite.

3. Three-component systems: silica–alumina–magnesia, silica–alumina–lime, silica–magnesia–lime, alumina–magnesia–lime.

4. Four-component systems (partial studies only): silica–alumina–magnesia–lime, silica–alumina–lime–soda, silica–alumina–potash–soda.

5. Five-component systems (partial studies only): silica–alumina–magnesia–lime–soda.

In view of the special knowledge and experience which the Geophysical Laboratory has obtained in dealing with the difficult problems connected with phase-rule investigations at high temperatures, it would certainly be advantageous if the direction and control of the work of a Division of Phase-Rule Investigations could be centered at this laboratory. In order to do this satisfactorily, it would probably be best to establish, if possible, a section in that laboratory for the special purpose of planning and conducting phase-rule investigations from the standpoint of the importance of these investigations to the subject of refractory materials. The work of the present staff of that laboratory is naturally inspired by geological interests and the phase-rule diagrams which have been worked out there are the result of the importance of these diagrams in their bearing upon geological and mineralogical problems rather than their importance in relation to refractory materials.

In addition to the actual experimental work which might be carried out at the Geophysical Laboratory in accordance with some coöperative arrangement, an advisory supervision and coordination of investigations along similar lines in other laboratories could to advantage be centered in the same institution which would thus become the headquarters for this Division.

In case the necessary arrangements could not be made with the Geophysical Laboratory, it would then be best, if possible, to center the work of this Division at one of the other institutions having well equipped ceramic laboratories. The Bureau of

Standards, the Bureau of Mines, the ceramic departments of several of the universities, and perhaps of certain private institutions should receive consideration in this connection.

10. **Division 3. Physical Constants.**—It would be the duty of this Division to compile all the available data concerning the physical, chemical and ceramic properties of refractory raw materials and manufactured products, to keep this compilation up-to-date in a readily accessible form, to promote the necessary investigations for increasing our knowledge of such properties, and to secure the coöperation of all investigators in this field to the end that experimental methods might be improved and standardized, and undesirable duplication avoided. Eventually this Division might desire to establish a laboratory of its own or arrange to have its work carried out by special arrangements with some existing laboratory, such for example as the Bureau of Standards.

11. **Division 4. Standard Methods for Testing Refractory Products.**—The function of this Division would be the development of standard methods for testing products in order that the results of such tests should indicate as clearly as possible the behavior which might be expected of each material under service conditions. The methods to be employed in testing a given material would naturally vary according to the use to which the material was to be put. The work of this Division should be correlated with that of the American Society for Testing Materials and the corresponding committees of the American Ceramic Society. For a time at least, the experimental investigations might be carried out by enlisting the coöperation of a number of different laboratories and the work might to advantage be centered at the Bureau of Standards.

The work of Divisions 3 and 4 deals with questions which are probably the most pressing ones at the present time. That is, an accurate and complete knowledge of the properties of refractory materials and products and the development of tests which will accurately depict the behavior of these materials under service conditions are very much needed.

12. **Division 5. Raw Materials Specifications.**—This Division would formulate the specifications to be met by each raw material employed in the manufacture of each type of refractory product. These specifications would cover such factors as chemical and mineralogical composition, crystallographic condition, texture, state of mechanical division, fusibility, and all the important ceramic properties such as plasticity, burning behavior, properties developed on burning, etc. The work of this Division might also be carried on for a time and perhaps permanently by coöperative arrangements with existing laboratories.

13. **Division 6. Manufacturing Methods.**—This Division would study the processes employed in manufacturing each type of refractory and recommend such changes as would result in improvements in quality, decreased cost of production and increased definition and standardization of product. Every effort should be made to design and manufacture refractories adapted to the special requirements of the furnace in which they are to be used. That is, insofar as commercially practicable, the refractory should in each instance be made for the furnace, not the furnace for the refractory. In an actual working organization, it would perhaps be desirable to unite Divisions 5 and 6.

14. **Division 7. Standard Specifications for Refractory Products.**—This Division, as well as Divisions 4 and 6 above, should probably be organized in sections, with a section for each industry requiring a special class of refractories. Among the most important users of refractory products which would be represented by sections in this Division, are:

1. The iron and steel industry.
2. The various non-ferrous metal industries.
3. The gas industry.
4. The by-product coke industries.
5. The glass industry.
6. The pottery and porcelain industries.
7. The brick, tile and sewer pipe industries.
8. The cement industry.
9. The various industries employing electric furnaces.
10. The enameling industries.

11. The great variety of chemical industries.

12. Power plants.

Each section would draw up the specifications which should be met by each type of refractory required in the corresponding industry.

The labors of this Division should be closely correlated with those of Divisions 3, 4 and 6, the work of which would, to a large degree, constitute the foundations upon which this Division would build. In a working organization, it would perhaps be desirable to unite Divisions 4 and 7.

15. **Division 8. The Engineering Division.**—The principal work of this Division would be in connection with the design and methods of operation of industrial kilns and furnaces, the purpose being to establish the best design of furnace or kiln and the most efficient method of operating the same for each particular industry or process employing high temperatures. This Division would perhaps be organized in sections corresponding to the various types of furnaces required. Owing to the large scale experiments involved in research in this field, it is clear that large expenditures would be required for carrying out any extensive research program.

16. **Division 9. Geology and Mining.**—The function of this Division would be to promote the extension of geological surveys looking toward the location and mapping of deposits of refractory raw materials, to investigate any other geological problems of importance to the subject, and to secure the further study and development and greater utilization of improved methods of mining, handling and preparing these materials. This Division should coöperate with the United States Geological Survey, the United States Bureau of Mines, the Association of American State Geologists, and the National Research Council, which organizations have recently formulated and are putting into effect a plan for a coöperative survey of the ceramic resources of the country. A description of this plan is contained in the proceedings of the Pittsburgh Conference.[1] This Division would coöperate closely with Division 5.

[1] *The Clayworker*, **69**, 759 (1918).

17. Division 10. Coördination and International Coöperation.—This Division would be composed of the chiefs of each of the other Divisions together with representatives of the National Research Council, and possibly of other organizations, under the presidency of the Scientific Director. It would be the duty of this Division to see that the necessary coördination was secured in the labors of each of the other Divisions and to promote any desirable international coöperation in refractory materials research. The headquarters of this Division might advantageously be located at Washington, and as far as international relations are concerned, the work of the Division could perhaps be most conveniently transacted through the international connections already established by the National Research Council.

This Division might also prepare a research census of all agencies engaged in refractories research and arrange to receive regular reports of progress.

An organization for coöperative research in refractory materials seems to be in process of formation in England and a report dealing with (*a*) Refractory materials required by the various industries; (*b*) The laboratory facilities available for refractory research in public institutions of Great Britain and Ireland; (*c*) The facilities existing in England for collecting and publishing information on refractory materials; (*d*) The problems calling for the most important action; and (*e*) The special requirements of each industry, was adopted by a conference held at London, in July, 1917, and has been published.

The ceramic industries of France have also recently formed an association known as the *Syndicat des Fabricants de Produits Ceramiques de France* and coöperative relations should be established with the refractories section of this association.

18. Financing the Research Organization.—An organization constituted in accordance with some such scheme as that outlined in the foregoing pages would require liberal financial provision for its operation. Ample financial resources for inaugurating the undertaking might be secured if each producer of refractory materials or products would contribute to a common fund an annual self-imposed tax of say 2/10 of 1 per cent of the annual

sales value of his output. In comparison with the tax which his business pays to state and nation, to fire, risk, and liability companies in the form of insurance premiums, and to legal counsel in the form of retaining fees, a research tax of 2/10 of 1 per cent is insignificant. Such a tax would provide an annual income of over $100,000 for a Refractories Research Corporation, and this income would automatically increase from year to year with the growth of the industry. If users of refractories, as well as producers, were admitted to the organization (and this would be highly desirable) the above estimated annual income of the Research Corporation could be increased by more than 50 per cent, by a similar rate of taxation on the annual purchase value of all refractories purchased by each user.

In this connection the following paragraphs from a recent address delivered by Dr. John Johnston before the American Zinc Institute are much to the point:

"Most large firms take out insurance of various kinds and make regular allowance for depreciation of plant and equipment; comparatively few make expenditures on research as a fixed charge on their business. And yet this insurance against ignorance is comparatively cheap; one large firm considers it certain that the amount gained directly from their research work—without taking into account the less tangible, though certain, benefits—has been *at least* ten times its cost. But to get the full benefit of such insurance it is necessary to go systematically into the fundamentals of the question, to ascertain precisely what is happening at each stage of the operation. The absolute necessity of such fundamental work is insisted upon by all of the big firms which have gone into systematic research work and found it profitable. This implies a fairly large expenditure which, though a relatively small matter for a large firm, would not be possible to a small firm because it would constitute too large a charge on its total annual product. But smaller units may organize to carry out research work coöperatively, and so gain equal, if not greater, advantage at a comparatively small cost to each individual unit."

"The National Canners Association some years ago established in Washington a laboratory to take up some of the difficulties of the canning industry; and this laboratory has been so suc-

cessful that it is now considered to be one of the assets of the industry. In Britain the plan of establishing a coöperative research organization is being considered by a number of industries; the most substantial progress has been made by the cotton industry, a provisional committee of which has worked out a scheme of procedure in considerable detail. They are establishing the British Cotton Research Association that will include as members, cotton-spinning and thread-making firms, manufacturers of cloth, lace and hosiery, bleachers, dyers, printers and finishers; it will conduct researches which include the study of the cotton plant at one end and the 'finishing' of the manufactured article at the other, and also encourage and improve the education of persons who are, or may be engaged in the industry. They have published a very interesting pamphlet[1] on 'Scientific Research in Relation to Cotton and the Cotton Industry,' in which a popular account of the matter is given. It would lead too far to go into the matter but this report brings out one important point deserving of mention here—namely, with respect to the cost of such research work to each member of the Association. On the basis that the Association would spend $250,000 a year on research work, it is shown that the cost to each member would be only about 10 per cent of his fire insurance premium, 25 per cent of the cost of health insurance, or about 20 per cent of the cost of employers' liability insurance. In other words, the scientific and technical health of the industry can be insured at a very small cost."

The organization of most of the Divisions would naturally be a gradual process dependent in each instance upon the finding of the right man to head the Division and the working out of a definite research program which would receive the approval of the Board of Trustees. Any attempt to create from the beginning a full fledged organization, such as that outlined above, would probably result in numerous disappointments. A not improbable eventual development of the work might be the establishment of a large central laboratory and testing station in which all of the research work of the Association would be carried out. The experience of several of the large corporations, such as the General

[1] Copies obtainable from the Secretary, 108 Deansgate, Manchester; (price nine pence).

Electric Company and the Eastman Kodak Company, and of the National Canners Association, has demonstrated the success of this method of conducting industrial research. Some of the obvious advantages of this concentrated form of organization over the distributed type of organization are (1) the opportunity for frequent personal conferences among the different types of experts on the staff; (2) the avoidance of duplication of equipment; (3) the saving of the time and energy of the Director. The first of these is probably the greatest virtue of the concentrated form of organization and is the one to which its great success is most largely due.

19. The Practicability of Forming a Refractories Research Corporation.—Whether and in how far it is feasible, under the industrial and economic conditions which exist in the refractories industries at the present time, to form a research corporation for the purpose of prosecuting coöperative research in this field could probably only finally be determined by attempting to form such an organization. Viewed purely from the scientific side, the field is a sufficiently homogenous one to make such an organization practicable and desirable, but viewed from the industrial and commercial side, this can hardly be said to be the case. The manufacturers themselves and many of the users of refractory materials are industrial competitors and this element of competition is alone sufficient to make the actual realization of any such plan as that proposed here extremely difficult, if not quite impossible. Industrially and commercially the field is a very heterogeneous one, involving many diverse and conflicting interests. Some of the larger manufacturers already have their own research laboratories for dealing with the problems peculiar to their own product, and the first interest of each manufacturer is naturally the well being of his own business rather than the development and perfection of our knowledge of refracto y materials in general.

The preparation of any research budget to be defrayed by appropriations from a common fund contributed to by *all* manufacturers and users of refractories would present almost insuperable difficulties. Perhaps the only Divisions in which anything

like unanimous agreement as to expenditures could be secured would be Divisions 1 and 9. In the case of the other Divisions it would seem that a budget could be agreed upon only if the expenses of the different undertakings in each Division were defrayed by those manufacturers and users to whom the results of these particular investigations would be of direct and immediate value. For example, to take an extreme case, one could hardly expect that the manufacturers of clay refractories would be especially interested in helping to defray the expenses of an investigation of boron nitride as a refractory. Certainly if any part of a common fund were used in this way, any contribution of the manufacturers of clay refractories towards such investigations would be a purely altruistic one. Furthermore, any common fund created by contributions based upon the sales and purchase value of products would in large part be made up of contributions from manufacturers and users of a comparatively small number of types of refractories, since most of the tonnage of refractories used in modern industry consists of clay and silica materials, and these contributors would naturally be primarily interested only in investigations dealing with these particular classes of refractories. For the same reasons any considerable expenditure for the work of Division 2, for example, could hardly be expected from other than altruistic motives, since the phase-rule diagrams for the refractory materials most largely used and for which the necessary tonnage of raw materials is in sight have already been worked out and hence the development of any refractory which would to any considerable degree replace any of these materials would only be commercially possible in case it had a much longer life under service conditions than the types of refractories now employed.

Moreover, it could hardly be expected that the manufacturers of a given type of refractory would be interested in promoting an investigation which might conceivably result in the perfection of a product of sufficient commercial practicability to destroy or to greatly injure their own business, however desirable from a national viewpoint such a result might be. Certainly such investigations could be undertaken only if adequate provisions for safe-guarding the financial interests of all members against

such possibilities as the above could be worked out. A single industrial corporation, such for example as the General Electric Company, can undertake investigations leading to the development of products which might require the scrapping of manufacturing facilities representing large investments, but for an association of more or less competitive interests to undertake any such investigations on a coöperative basis has obviously great difficulties, especially if both manufacturers and users are included in the organization. These difficulties would, it is true, be greatly diminished if the association included only users of refractory materials, and for this reason it may be that the country will eventually have to look to the consumers of refractories for the prosecution in a large way of systematic research in this field.

It seems clear to the writer that any such organization as the "ideal" one presented in the preceding pages could scarcely be developed even eventually except by private or governmental endowment or by the actual industrial amalgamation of all or the greater part of the refractories interests of the country. In view of these facts it may be that the above survey of the scientific aspects of the subject has no practical value at the present time, but if it serves only to promote discussion, to arouse further interest in research in this field, and to bring about any further degree of coöperation, its purpose will be fulfilled. Some type of organization for accomplishing at least a portion of the work outlined above ought to be feasible. Perhaps several more or less independent organizations, instead of one, would be required, or perhaps an association of research laboratories engaged in refractories research might be able to perfect some practicable scheme of coöperation. Certainly, viewed solely from a national economic viewpoint, the stimulation of research in this field is greatly needed, and in addition to supporting the investigation of those problems which seem most urgent from the "practical" viewpoint, it is to be hoped that to some degree at least manufacturers and users of refractories will be willing to make some contributions from more purely altruistic motives; that is, that they will feel ready to take some share in the promotion of all classes of investigations in their field, even though they see no possibility of direct or immediate financial return to themselves.

Such contribution might take the form of direct financial assistance or the form of supporting the efforts of federal, state and endowed institutions to secure larger appropriations for carrying out some of the more fundamental scientific work, even though some of this work may seem to be largely of the type ordinarily classed as "pure science," and perhaps appear to be more or less visionary or "impractical." Certainly the history of the development of science and industry has repeatedly demonstrated the enormous ultimate value of research work of this character.

THE RELATIVE ACTION OF ACIDS ON ENAMELS—III.

By E. P. Poste.

Introduction.

The action of acids on enamel surfaces is a matter of continued interest to those engaged in the various phases of enamel technology as well as to anyone who is engaged in the manufacture of a glass or a silicious protective coating which is to withstand the attack of acids. The importance of the subject has brought about the need for some standard test for acid resistance and one which can be generally accepted and by means of which wares can be compared by different parties in such a manner as to secure accurately comparable results.

The Sub-Committee on Enamels of the Committee on Standards of the American Ceramic Society has been assigned a task of this kind and, while the work is not sufficiently advanced to take the form of a report, some preliminary efforts which throw considerable additional light on the general subject under consideration have been made. Before treating in a detailed way the results of the present work it will be well to refer briefly to records of previous investigations.

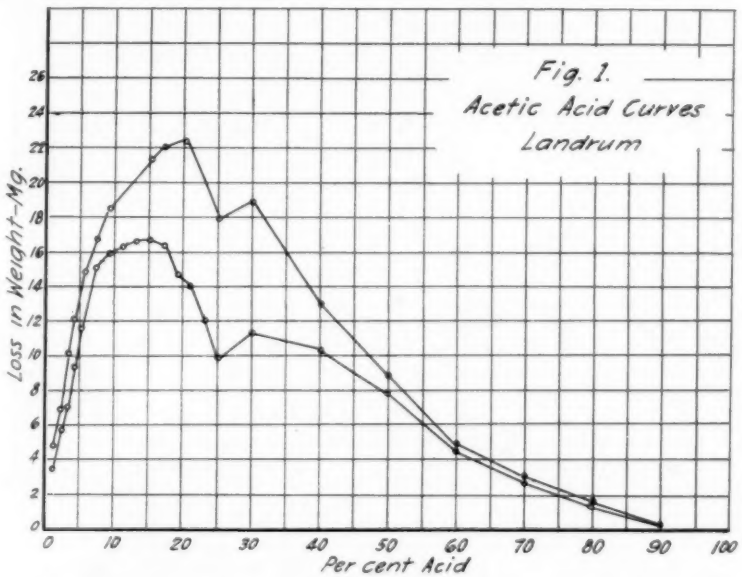
Previous Investigations.

Definite information as to the actual nature of the action of an acid on an enamel has been recorded by R. D. Landrum.[1] His method of testing was to evaporate to dryness various initial concentrations of acetic acid in small enameled basins and to determine the loss in weight due to the action of the acid under these conditions. The curves which he obtained from two series of such tests are shown in Fig. 1. Landrum's general conclusion was that the maximum activity took place in the case of an acid approximately 20 per cent in original strength and that the action rapidly diminished as the initial acid approached a concentrated

[1] *Trans. Am. Ceram. Soc.*, **13**, 494–501 (1911).

solution. He noted, at about 25 per cent, a definite irregularity in the curve. This he was able to check upon repeated trials.

The next quantitative data reported were published by the writer.[1] The method used was to expose a sample of standard enamel frit to the various strengths of acids under standard conditions and to determine the loss in weight. It was demonstrated in general that the maximum activity of an acid on an enamel took place at concentrations of from 10 to 20 per cent. This fact was re-



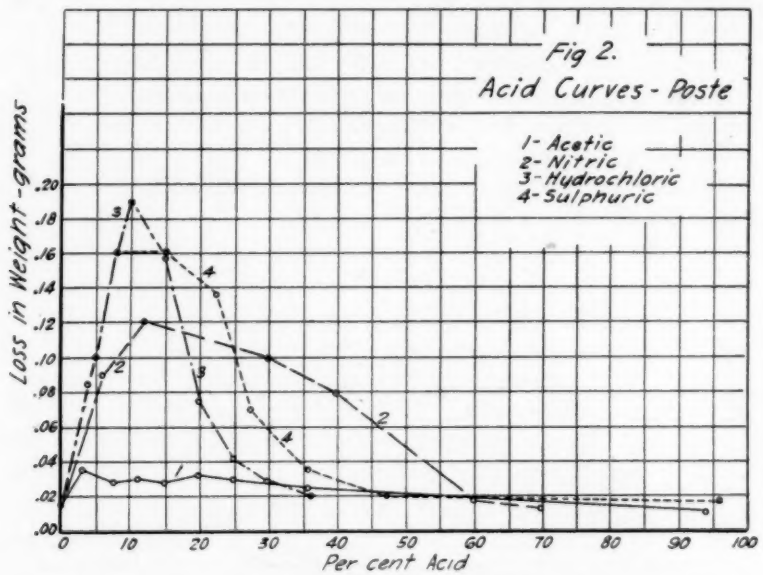
demonstrated relative to acetic acid and was extended to include sulphuric, nitric and hydrochloric acids. The results are shown in Fig. 2.

A second paper by the present author[2] was fundamentally an answer to the discussion of the first paper and indicated the effect of the various possible irregularities in the method—which as a whole has been rather severely criticised as not being of particular value in the determination of the acid resistance of finished enamels.

[1] E. P. Poste, *Trans. Am. Ceram. Soc.*, **17**, 137–149 (1915).

[2] E. P. Poste, *Ibid.*, **18**, 570–574 (1916).

An investigation has also been reported by Leon J. Frost[1] who presented data resulting from a study of the action of acetic acid solutions of varying strengths on finished enamel surfaces. The method used was essentially the same as that which has been used by Landrum—varying only in the manner of heating. The curve which Frost obtained is shown in Fig. 3. He confirms the conclusions already drawn and, besides checking in a general



way the irregularity in the curve as noted by Landrum, he reports several other irregularities occurring at lower concentrations.

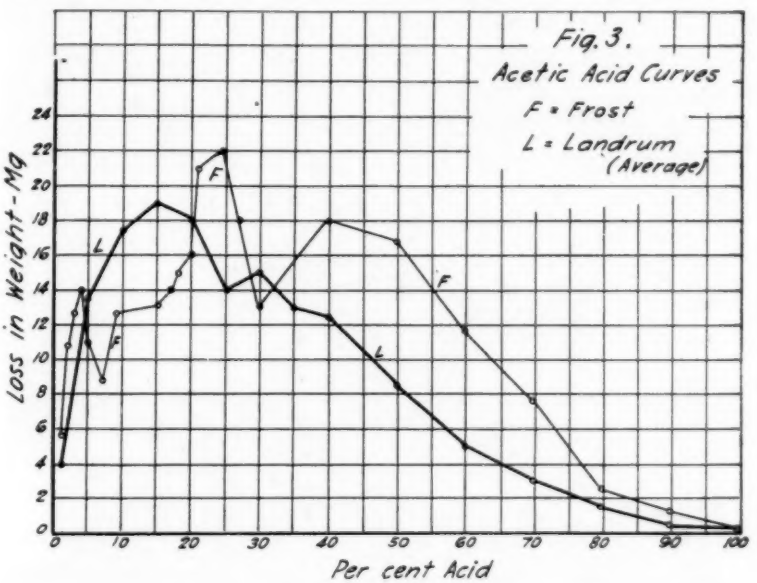
Present Investigation.

The work of the Sub-Committee on Enamels has included a review of the status of the situation as outlined above and a consideration of the fundamentals upon which an acceptable test should be based. This has been followed by certain experimental work. As one of the fundamentals, the members of the Committee have agreed that an acid to be used in a standard test should be one which can be obtained at the average drug store and made

[1] THIS JOURNAL, 1, 422 (1918).

up to a given strength by the practical man without introducing errors which would exceed a reasonable limit of experimental error in the final results of the test.

After considerable discussion of this phase of the question it appeared that a material which could be bought in the solid form and added to a certain amount of water, thus producing a standard solution of the pre-determined strength, would be much preferable to an acid purchased in the liquid condition which would be much more liable to variation in strength. It would of course



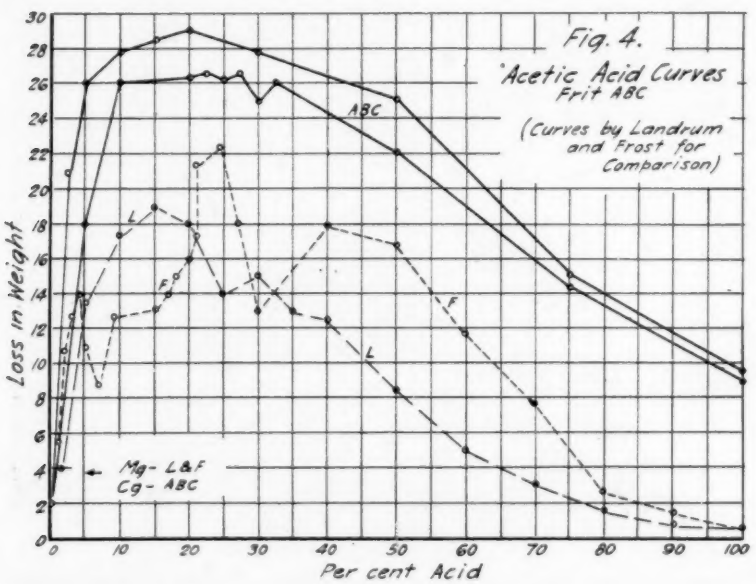
be pre-requisite that such a solid reagent as obtained from normal stock should be reasonably uniform in its composition. The data presented in this paper are those which have resulted from studies along these lines.

Enameled cooking ware is very often called upon to resist the action of citric and tartaric acids and as these promised to be of value as a basis for a standard test they were chosen as a basis of study. The preliminary work of the Committee to date has included a determination of the characteristic behavior

of these acids towards enamels. Their stability under storage conditions has also been investigated.

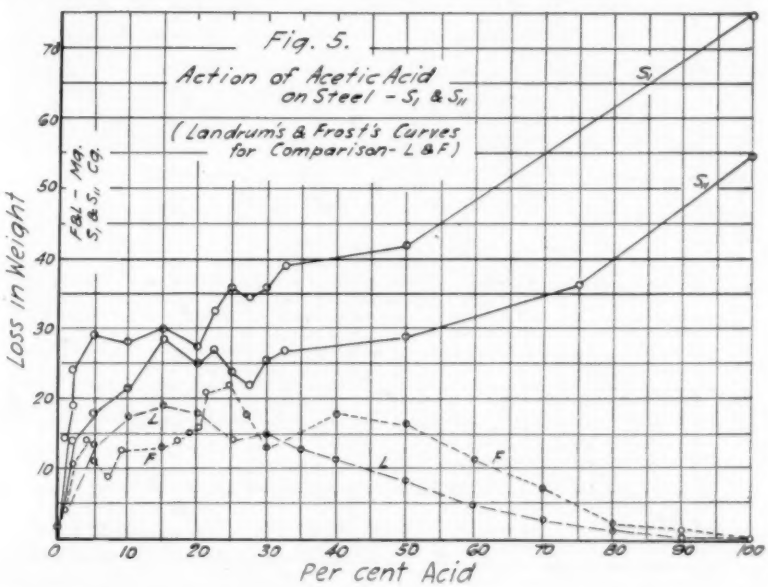
As a basis of such work five frits were used. They were designated as Ex. 1, Ex. 2, A, B and C. Ex. 1 and Ex. 2 were two experimental blue frits of low acid resistance as compared with cooking-ware frits. A, B and C were three commercial white frits submitted to the Committee by three enameling companies. A mixture of equal parts of these was designated as ABC.

Action of Acetic Acid.—In an effort to correlate the previous data on acetic acid with the action of acetic acid on the enamels



under consideration, several series of tests were made—using a mixture of equal parts of the above mentioned frits (A, B and C). A frit tested under standard conditions gave the curve shown in Fig. 4, in which are also reproduced the curves of Landrum and Frost. It will be noted that the general nature of the curves is quite uniform although the action of the acid at higher concentrations appears to have been relatively more severe than the action on the enamels used in previous work.

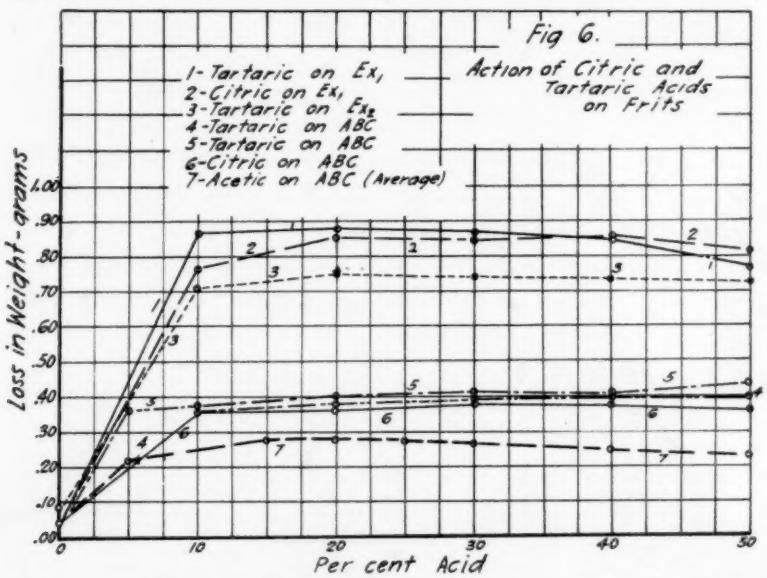
At this point it seemed well to note the action of acetic acid on freshly cleaned steel surfaces and two series of tests were run on small basins, the losses in weight of which were determined gravimetrically. These basins were exposed to equal amounts of various strengths of acetic acid at laboratory temperatures for 24 hours. The results are plotted in Fig. 5, the two curves representing two different tests, presented separately rather than as one curve representing the average, in order to show their similar nature. The numerical difference was due to a higher average temperature in one case than in the other. It is interesting



to note the parallel irregularities up to 30 per cent which suggest a relation to the irregularities obtained by Frost and Landrum. Their curves have been reproduced on this figure for reference in connection with this point. It will further be noted that the acetic acid at higher concentrations acted very severely on the steel as compared with the more dilute solutions—which is in accordance with the generally accepted fact that the acetic acid has a particularly strong corrosive action on steel, even in the absence of water.

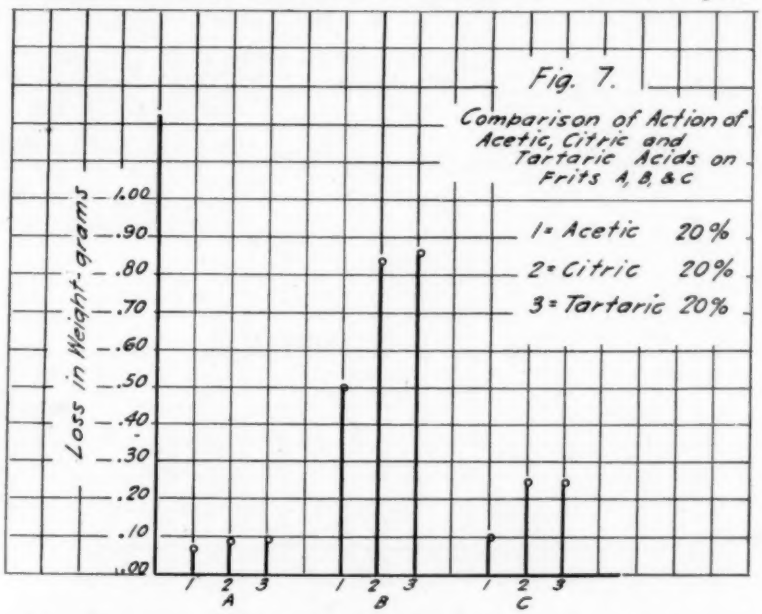
Action of Citric and Tartaric Acids.—The investigation as to the action of tartaric acid included tests on the three frits, Ex. 1, Ex. 2 and ABC, the results of which are shown in Fig. 6. Similar concentrations of citric acid were used on the frits Ex. 1 and ABC, the results of which are also shown in Fig. 6 as well as the acetic acid curve for ABC.

Two general observations may be made. One is the fact that enamels of different acid resistance behave quite differently when subjected to the action of either citric or tartaric acid. This fact is very evident from the characteristic difference between the curves for frits Ex. 1 and Ex. 2 and those for frit ABC. It



is also very apparent that the relative action of citric and tartaric acids on the combined frit ABC is not materially different and that in concentrations, from 10 per cent up to saturation, the severity of the action is quite constant. It would seem that the above tests have established in a general way the nature of the action of citric and tartaric acids on the particular frits used and that the activity of a 20 per cent solution was quite high, without any very radical changes due to slight differences in acid concentrations in either direction being in evidence.

The next test was to run separately on 20 per cent acetic, tartaric and citric acids, each of the three frits which had been previously used in the mixture ABC. The results of these tests are shown in Fig. 7 from which it will be seen that frit A is of relatively high acid resistance, being practically equally resistant to 20 per cent solutions of acetic, citric and tartaric acids. Frit B is much less resistant than frit A and considerably less resistant to tartaric and citric acid than to acetic acid. Frit C is quite

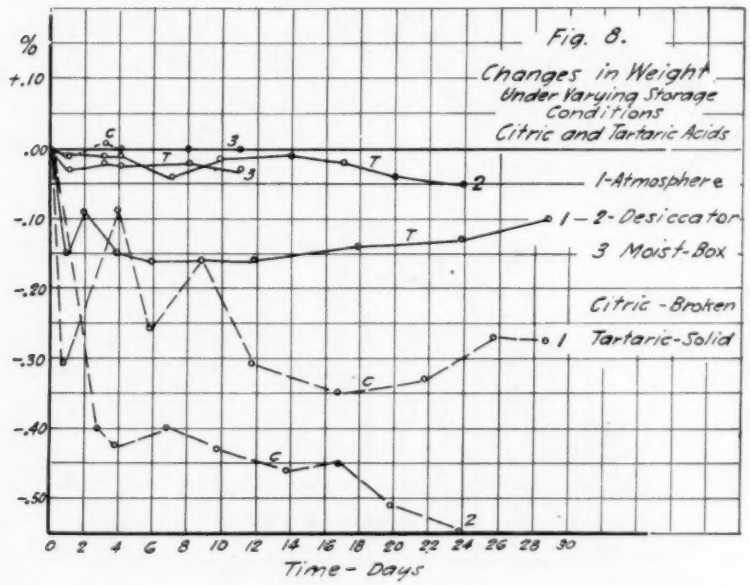


resistant to acetic acid and much less resistant to tartaric and citric acids.

Variation in Composition of Citric and Tartaric Acids.—To determine the possibility of obtaining either citric or tartaric acid which would be quite uniform in strength, two lines of investigation were carried out. The first method was to expose 5-gram samples of tartaric and citric acids to varying atmospheric conditions over a sufficiently long period of time to determine any tendency to change in weight; the second was to procure from local drug stores several samples of citric and tartaric acids

and to compare their compositions, assuming that they may have been subject to variations in storage conditions.

The results of the former tests are shown in Fig. 8. The curves marked 1 show on a percentage basis the change in weight of citric and tartaric acids when exposed to the laboratory atmosphere during the month of December, at which time the room was maintained at a temperature approximating 20° C, but owing to various operations going on in the room the humidity was

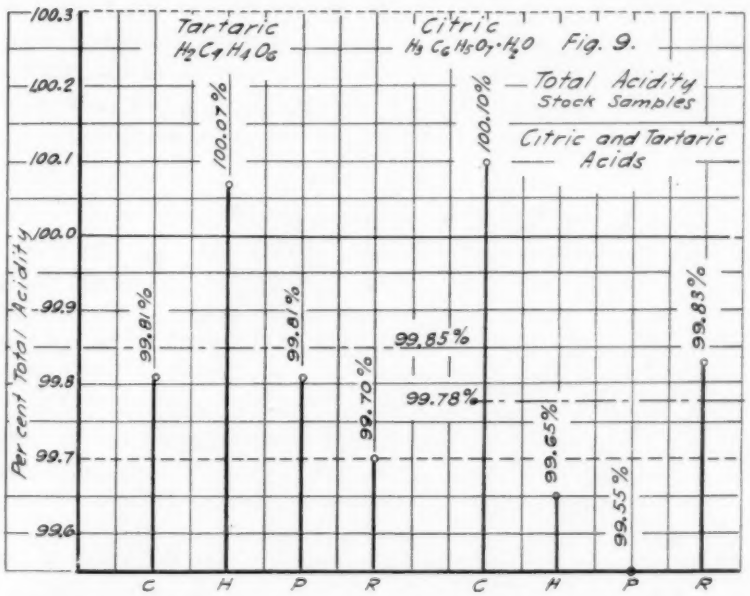


no doubt relatively high. It will be seen that the citric acid lost weight up to about 0.3 per cent, beyond which no very material change took place, and that the tartaric acid lost weight to about 0.15 per cent—beyond which it was reasonably uniform.

The curves marked 2 (Fig. 8) were plotted from the results of similar tests made upon samples which were placed in a desiccator over calcium chloride. It will be noted that the citric acid lost weight quite rapidly to about 0.4 per cent and continued to lose somewhat gradually from that point on while tartaric acid lost but very slightly, the maximum being about 0.05 per

cent. The curves marked 3 were plotted from the results of a test in which the two materials were exposed in a moist box to a humidity approximating 85 per cent (as determined by the wet- and dry-bulb thermometer method) at temperatures ranging from 15° to 20° C. It is quite apparent that there was no material change in weight, the tartaric acid losing slightly more than the citric acid but not over 0.03 per cent during the period of the test.

From these tests it would seem that tartaric acid is much less subject to changes, due to varying storage conditions, than is



citric acid. This fact is quite readily explained by a consideration of the chemical composition of these two materials. The formula of tartaric acid is $H_2C_4H_4O_6$ and that of citric acid $H_3C_6H_5O_7 \cdot H_2O$. In other words, the tartaric acid molecule does not contain water of crystallization while the citric acid molecule does have water of crystallization which is subject to partial loss when the acid is exposed to an atmosphere of low humidity.

The analytical data relative to the various samples of citric and tartaric acid are shown in Fig. 9 in which is indicated the

variations in total acid content of the various samples obtained. It will be noted that the total acidity figure for tartaric acid ranged from 99.7 to 100.07 per cent, giving an average of 99.85 per cent, and that similar values for citric acid ranged from 99.55 to 100.10 per cent, giving an average of 99.78 per cent. These figures can only be taken to mean that both of these materials as tested conform to the theoretical composition within the limits of the analytical method used—which cannot be taken as accurate within plus or minus 0.3 per cent, the upper and lower limits of such error being designated by the two dotted lines at 100.3 per cent and 99.7 per cent, respectively. It will be noted that the average values for citric acid are slightly lower than those for tartaric acid but no significance can be attached to this fact in view of the slight difference as compared with the experimental error.

Conclusions.

The above review and further investigation relative to the action of acetic acid on enamels demonstrate the fact that the dilute acids are more active than the concentrated—the maximum being in the neighborhood of 20 per cent. The action of acetic acid in the neighborhood of its maximum activity on an enamel is subject to various irregularities. This has also been found true of the action of acetic acid on steel. This characteristic behavior of acetic acid would indicate that it is not desirable as an acid for a standard test in view of the fact that slight variations from a given strength would cause quite material differences in the activity of the acid on an enamel. A further objection to acetic acid would be the fact that it is a liquid which, when obtained from the average drug store, might vary quite materially in strength and hence analytical methods might be necessary in the preparation of a standard solution.

Owing to the fact that citric and tartaric acids are obtained in the solid form and are generally considered quite pure, they have been investigated and the following points brought out: First, at a given concentration citric and tartaric acids are more active on an enamel than is acetic acid and hence they give a more definite result in a given time. Second, the relative action of citric and tartaric acids at given concentrations appears to be about equal.

Third, the general shape of the curves for citric and tartaric acids is such as to render slight errors in concentration above 10 per cent of minor importance in terms of the difference in activity, *i. e.*, the curves from 10 per cent to 50 per cent are practically horizontal straight lines.

As a bearing on the relative merits of citric and tartaric acids for the proposed test, a study of the susceptibility of these two materials to changes in weight—due to varying storage conditions—has indicated very definitely that tartaric acid is much more stable than citric acid. In order to determine the probable variation on samples of commercial materials, four samples of each (citric and tartaric) obtained from stock and analyzed indicate that the variations—due to changes in moisture content which are liable to occur—are very slight, as a matter of fact they are within the limits of error of the analytical methods used, and at the same time so slight as to make practically no material difference on the action of the acid on the enamel, brought about by the slight variation in strength of a standard solution resulting from these irregularities.

We realize that the work which has been done along this line has been preliminary and that it has brought out several possible conditions which should be investigated further. Besides covering these points, the proposed line of procedure involves an effort to extend the tests to include the use of the proposed acids on actual enamel surfaces.

We will be very pleased to receive suggestions as to the relative desirability of using citric or tartaric acids in a standard test—in view of the general conclusion that either one of these acids would be appropriate so far as revealed by the data herein presented.

ELYRIA ENAMELED PRODUCTS CO.,
ELYRIA, OHIO.

COMPRESSIVE STRENGTH OF CEMENT-LIME MORTARS.[1]

By F. A. Kirkpatrick and W. B. Orange.

Introduction.

Cement mortars have been made the subject of many investigations, as a result of which the laws governing the strength of such mortars are quite well understood.

It is not known, however, whether these laws hold when hydrated lime is included as a constituent of cement mortar. Very few investigations have been made of cement-lime mortars and none of them has had as its object the determination of the laws governing strength.

Macgregor[2] has determined the strength of a number of cement-lime mortars. He determined also the strength and moduli of elasticity of brick piers using such mortars. His principal conclusion was that the substitution by volume of hydrated lime in a 1 : 3 cement mortar caused decreases in strength for all amounts used. The strongest brick piers, however, were those made with mortars in which 10 to 50 per cent of the cement by volume had been replaced by hydrated lime.

Wig and Bates[3] determined the effect of the addition of waterproofing powders upon the compressive strength of 1 : 4, 1 : 6, and 1 : 8 portland cement mortars. Their conclusion in regard to strength was as follows: "The addition of the inert void fillers to mortars, as used in these tests, up to 20 per cent of the volume of cement, increases the compressive strength." The materials added included clay, feldspar, sand, hydrated lime and mixtures of these materials with organic substances.

A number of properties of cement-lime mortars were investi-

[1] By permission of the Director, Bureau of Standards.

[2] Bulletin J. of the Hydrated Lime Bureau, Pittsburgh, Pa., June 1, 1916.

[3] "Tests of the Absorption and Permeable Properties of Portland Cement Mortars and Concretes," Bureau of Standards, *Technologic Paper* 3.

gated by Emley.[1] The object of the investigation was stated to be twofold; first, to show the relations between properties of the mortars and the proportions of the ingredients; second, to illustrate the value of the triaxial diagram as a means of studying the properties of mortars.

The object of the present investigation was to determine what factors exert the greatest control over the strength of cement-lime mortars, to express the manner of control by a mathematical formula, and to indicate practical applications of the results.

Methods.

The following is a description of the materials used and of the methods employed in the experimental work.

Allegheny River sand, weighing 100 pounds per cubic foot and having a specific gravity of 2.65, was used. This material was of the following granulometric composition:

Per cent. passing sieve.	Mesh of sieve.	Size of opening. Inch.
100.0	20	0.034
88.2	30	0.0198
45.3	40	0.0150
10.5	60	0.0087
5.1	80	0.0068
3.1	100	0.0055
1.4	200	0.0029

A Western Pennsylvania portland cement was used. It had a specific gravity of 3.13 and was assumed to weigh 100 pounds per cubic foot.

An Indiana high calcium hydrated lime was employed. It had a specific gravity of 2.32 and weighed 40 pounds per cubic foot.

The mixtures were compounded upon the basis of the bulk volumes of the materials as given above, the water also being measured by volume. The compositions were chosen by means of the triaxial diagram as shown in Fig. 1. The figures shown at 5 per cent intervals are the designating numbers used for the compositions chosen. It should be noted that Figs. 1 and 4

[1] "Properties of Cement-Lime-Sand Mortars," *Proc. A. S. T. M.*, **17**, Part II, 261 (1917).

represent only one-quarter of the complete triaxial diagram but include most of the practical mortars.

The mortars were compounded carefully. The dry materials were weighed accurately and mixed thoroughly upon a mixing cloth. Water was then run in from a burette until the mixture

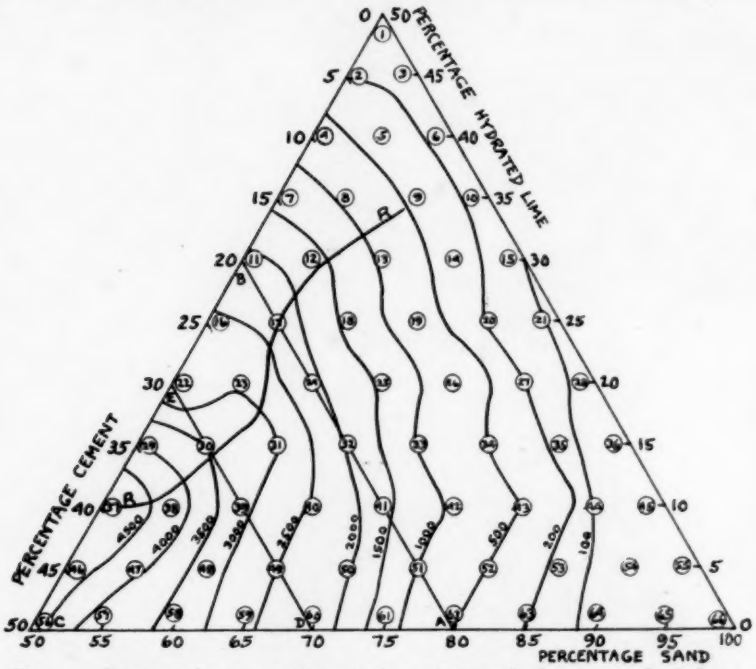


FIG. 1.—Compressive strength, pounds per square inch, at age of 28 days' air storage.

attained normal consistency as determined by the ball method. This method was carried out as follows:

A portion of the mortar was molded in the hands to the shape of a sphere, approximately two inches in diameter. When let fall upon a hard surface from a height of two feet, the ball must deform to a mass having a thickness of half its initial diameter. The mortar is then said to be of normal consistency. This determination could not be made for the very sandy mortars. These were brought as nearly to normal consistency as could be

judged by working them by hand and trowel. The method was hence somewhat unsatisfactory. The mortars were, of course, much less deformable than those used by the mason. It is suggested that for future investigations along this line, mortars of the consistency used by the mason be employed. Determination of the consistency of such mortars could be made more accurately. One method which has been attempted successfully for this purpose is that of filling a cylindrical mold with the mortar, pulling the mold up vertically, and measuring the height and diameter of the deformed mass of mortar. This method

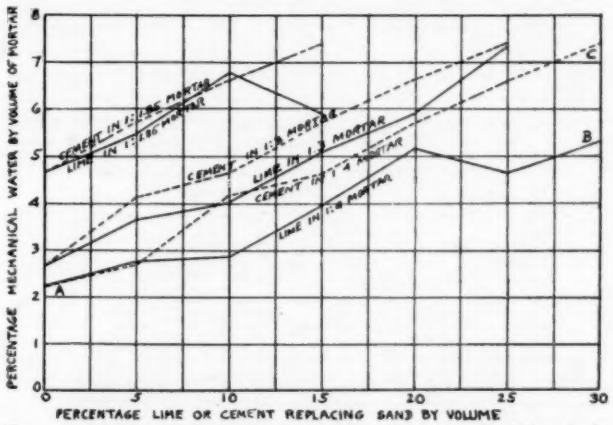


FIG. 2.—Mechanical water in mortars at age of 28 days' air storage. Proportions by volume.

can be used even for the more sandy mortars if they are brought to the soft consistency required by the mason.

As will be shown later, the maintenance of a standard consistency (measured in terms of deformability) in a series of mortars whose strength is to be studied is of practical value only—since strength does not vary with proportions of materials in the same manner as does consistency.

For each mortar composition chosen there were molded, in the customary cement gang-molds, six two-inch cubes. This was accomplished by forcing into the mold with the hands a large lump of the mortar which had been kneaded and rolled into a compact mass. The mold was then reversed and the other side

of the specimen subjected to pressure by the hands and more mortar used if necessary to fill the mold. The mold was weighed with and without the mortar, thus giving data for the calculation of weight per unit volume. As the results will show, the volume of the gang-mold remained sufficiently constant for our purposes. The specimens were allowed to stand in the molds in a moist place over night. They were then removed, three placed in water and three in air storage in the laboratory.

At the end of a 28-day storage period, the specimens were broken

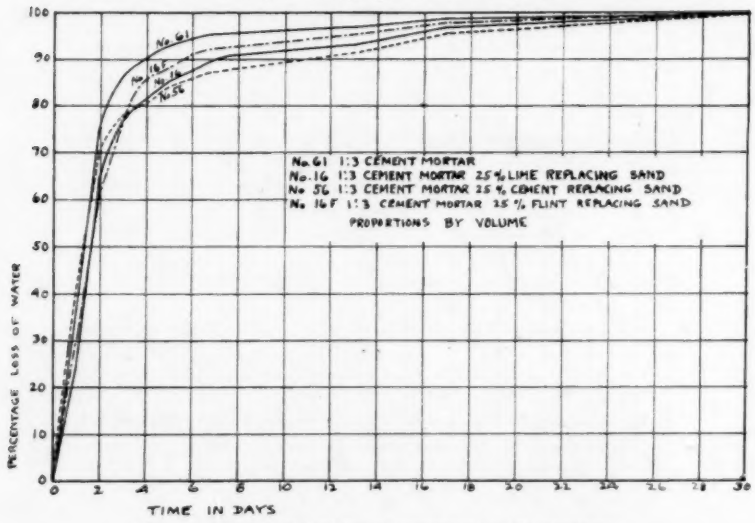


FIG. 3.—Rate of drying of mortars in air storage.

for crushing strength in a 10,000 pound hand-power Olsen testing machine. The broken pieces were used for determination of porosity by the usual method.[1] This consists in weighing the specimens after drying at 110° C, immersing them in water under a vacuum for at least 12 hours, then weighing wet, and weighing again suspended in water.

Discussion of Results.

The numerical results are presented in Table 1. Column No. 1 of this table gives the designation number of the mortars.

[1] R. C. Purdy, Illinois Geol. Surv., *Bull.* 9.

Columns Nos. 2 to 5 give the composition by bulk volume. Nos. 6 to 10 give numerical values representing the factors which govern the strength more or less accurately. Columns 11 and 12 give the compressive strength for air storage and water storage specimens.

Complete results for water storage mortars only will be presented

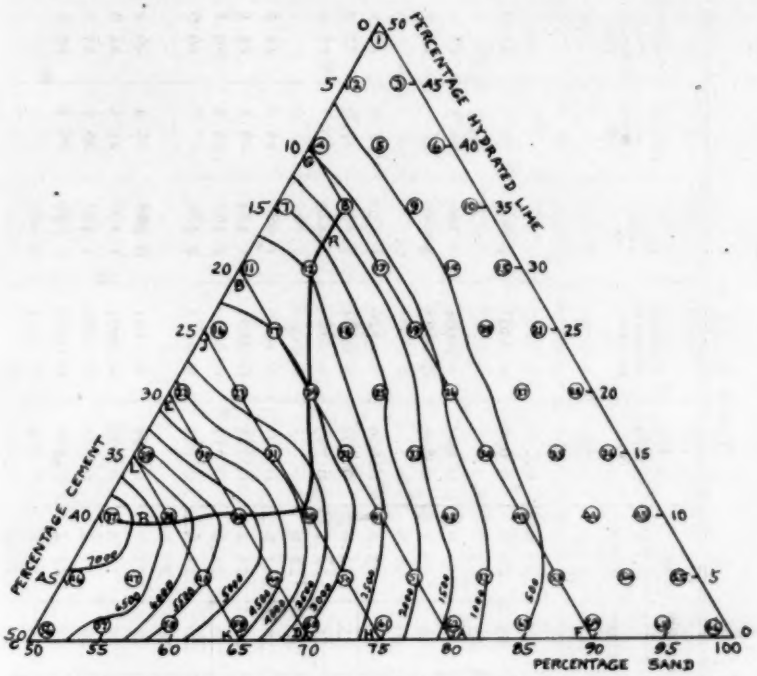


FIG. 4.—Compressive strength, pounds per square inch, at age of 28 days' water storage.

diagrammatically. There are two main reasons for this procedure: first, the systematic changes in properties are practically the same for either kind of storage; second, there is a maximum development of strength in water storage for most of the mortars.

Relations between Strength and Dry Bulk Composition.

The relations between strength and dry bulk composition of air storage mortars are shown in Fig. 1 and of water storage

TABLE 1.

No. (1)	Composition by bulk volume.				Density. (6)	Cement density product. (7)	Water ratio. (8)	Porosity, air storage. (9)	Porosity, water storage. (10)	Compressive strength, air storage. (11)	Compressive strength, water storage. (12)
	Sand. (2)	Cement. (3)	Lime. (4)	Water. (5)							
1	50	0	50	23.6	...	....	...	...	..	145	..
2	45	5	45	24.0	0.656	0.239	4.800	..	34.0	195	175
3	55	0	45	23.2	...	....	...	..	..	160	..
4	50	10	40	23.6	0.693	0.0494	2.360	29.5	28.0	700	925
5	55	5	40	23.2	0.676	0.0245	4.650	..	29.3	300	290
6	60	0	40	22.8	...	....	...	..	..	130	..
7	50	15	35	23.2	0.666	0.0726	1.550	27.8	25.5	1385	2095
8	55	10	35	22.8	0.702	0.0524	2.280	27.6	25.9	950	1250
9	60	5	35	22.1	0.713	0.0263	4.420	..	27.2	405	370
10	65	0	35	24.0	...	....	...	..	..	110	..
11	50	20	30	21.6	0.691	0.1010	1.080	25.2	23.7	2185	2975
12	55	15	30	21.2	0.715	0.0801	1.413	26.2	24.5	1670	2495
13	60	10	30	21.6	0.711	0.0522	2.160	25.5	26.2	950	1175
14	65	5	30	21.6	0.704	0.0254	4.320	..	26.6	280	420
15	70	0	30	23.6	...	....	...	..	..	100	..
16	50	25	25	23.2	0.681	0.1191	0.928	26.4	26.4	2580	3070
17	55	20	25	22.0	0.699	0.0992	1.100	25.5	24.6	2320	3030
18	60	15	25	22.4	0.711	0.0769	1.493	26.2	24.2	1365	2370
19	65	10	25	22.4	0.710	0.0503	2.240	26.4	25.5	675	1130
20	70	5	25	24.8	0.674	0.0235	4.960	..	..	180	200
21	75	0	25	22.4	...	....	...	..	..	75	..

22	50	30	20	23.2	0.687	0.1415	0.775	25.5	25.1	2585	4140
23	55	25	20	22.8	0.700	0.1218	0.910	24.6	25.1	2925	3145
24	60	20	20	23.2	0.710	0.0994	1.160	25.5	26.3	2145	3060
25	65	15	20	22.4	0.711	0.0741	1.490	26.8	25.8	1415	2115
26	70	10	20	23.6	0.694	0.0465	2.360	..	27.4	765	890
27	75	5	20	24.0	0.690	0.0228	4.800	..	..	205	210
28	80	0	20	24.8	...	....	...	..	..	50	..
29	50	35	15	22.1	0.712	0.1738	0.631	23.0	18.6	4110	5970
30	55	30	15	21.7	0.716	0.1490	0.723	23.0	20.1	3480	4565
31	60	25	15	22.1	0.716	0.1232	0.882	24.2	23.5	3110	3885
32	65	20	15	23.2	0.700	0.0931	1.160	25.5	25.6	1925	2750
33	70	15	15	24.0	0.688	0.0670	1.600	27.6	27.2	970	1560
34	75	10	15	23.2	0.689	0.0445	2.320	29.5	29.0	485	650
35	80	5	15	24.8	0.668	0.0200	4.960	..	30.2	150	140
36	85	0	15	..	...	....	...	..	..	..	..
37	50	40	10	22.8	0.731	0.2100	0.570	22.9	17.9	5090	7540
38	55	35	10	22.8	0.726	0.1760	0.650	23.1	14.8	4340	6440
39	60	30	10	22.8	0.715	0.1502	0.760	24.0	18.8	3105	5300
40	65	25	10	22.8	0.724	0.1223	0.911	25.0	21.0	2540	3910
41	70	20	10	22.8	0.693	0.0794	1.140	25.9	23.9	1720	2570
42	75	15	10	23.6	0.705	0.0684	1.572	27.4	26.3	910	1355
43	80	10	10	23.2	0.685	0.0429	2.320	30.0	30.5	485	585
44	85	5	10	24.7	0.641	0.0186	4.950	..	29.2	100	120
45	90	0	10	..	...	....	...	..	..	..	..
46	50	45	5	23.6	0.708	0.2113	0.525	23.2	20.8	4800	6920
47	55	40	5	22.7	0.717	0.1918	0.570	23.1	20.5	4150	6790
48	60	35	5	22.4	0.709	0.1624	0.640	24.4	21.8	3210	5540
49	65	30	5	22.0	0.717	0.1390	0.734	24.7	22.2	2490	4810

TABLE 1—(*Continued*).

No. (1).	Composition by bulk volume.				Density. (6)	Cement density product. (7)	Water ratio. (8)	Porosity, air storage. (9)	Porosity, water storage. (10)	Compressive strength, air storage. (11)	Compressive strength, water storage. (12)
	Sand. (2)	Cement. (3)	Lime. (4)	Water. (5)							
50.....	70	25	5	23.7	0.711	0.1150	0.947	25.2	24.6	2110	2800
51.....	75	20	5	24.8	0.700	0.0882	1.24	27.4	25.3	940	2040
52.....	80	15	5	26.8	0.678	0.0616	1.788	29.5	28.5	465	1015
53.....	85	10	5	27.2	0.646	0.0370	2.720	23.3	30.6	150	375
54.....	90	5	5	30.0	0.628	0.0186	6.000	..	..	30	60
55.....	95	0	5	..	...	....	...	..	..	..	..
56.....	50	50	0	24.0	0.715	0.2328	0.480	21.4	16.3	4760	6830
57.....	55	45	0	23.6	0.707	0.2050	0.525	23.4	17.7	3580	6260
58.....	60	40	0	22.8	0.707	0.1837	0.570	22.1	18.8	3475	5180
59.....	65	35	0	23.0	0.706	0.1560	0.658	24.2	20.3	2545	4380
60.....	70	30	0	24.3	0.699	0.1312	0.810	26.1	23.6	2330	2850
61.....	75	25	0	23.2	0.682	0.1023	0.925	27.2	25.8	1225	2370
62.....	80	20	0	26.0	0.657	0.0706	1.300	30.4	27.6	440	1330
63.....	85	15	0	28.0	0.643	0.0544	1.867	..	32.1	200	500
64.....	90	10	0	32.0	0.618	0.0328	3.200	..	..	65	125
65.....	95	5	0	32.4	0.621	0.0164	6.88	..	..	15	25
66.....	100	0	0	..	...	....	...	..	..	..	..

mortars in Fig. 4. The percentage compositions of the mixtures may be read from these diagrams or found by reference to the proper designating number in Table 1.

The triaxial method of representation is unsatisfactory for the purpose of a theoretical study of the properties of cement-lime mortars. Since there are four constituents in these mortars, it would be necessary to produce four triaxial diagrams in order to provide for all the possible combinations of three constituents each. The writers have found that these four diagrams give little satisfactory theoretical information.

Since the contour or iso-strength lines of Fig. 4 appear to run their courses in a uniform manner, it would seem that there must be a definite law governing their directions. As will be shown later, such a law exists and depends fundamentally upon the density of the mortars. Since both strength and density cannot be represented at the same time in the triaxial diagram of Fig. 4, the operation of the law governing strength cannot be satisfactorily observed by means of this diagram.

Effect of Replacing Sand by Cement or Lime.

Before taking up the theoretical discussion it is desired to consider the practical significance of the results presented in Figs. 1 and 4.

The claim is often made, by advocates of the use of hydrated lime in mortars and concretes, that the lime takes up water which it retains and later gives up to the cement for hydration, thus causing increase in strength. In Fig. 2 is shown diagrammatically the amount of mechanically held water found in some of the mortars after 28 days' storage in air. This was determined by drying the mortars at 110° C, then measuring their volumes. The loss of weight in drying was then calculated as percentage of the volume of the mortar.

If any unusual amount of water is retained by the lime under any conditions, it should be distinctly noticeable in these mortars. They were dried in air, thus affording the lime full opportunity to exhibit its water-retaining ability. The 28-day period was not too short nor too long for the experiment. At this age the lime should be at the height of its strength-producing activity—since

the strength of cement mortars and concretes does not reach its maximum until an age of from 90 days to one year.

The strengths of the mortars represented in Fig. 2 may be found by reference to Fig 1. For example, mortars represented on the lines AB and AC in Fig. 2 have compositions indicated by points on the lines AB and AC in Fig. 1. Strength is discussed elsewhere but it is seen from Fig. 2 that although replacement of sand by lime causes an increase in the amount of mechanical water present, replacement of sand by cement shows a greater increase. It is evident that these results do not support the theory of retention of water by lime in mortars.

The results of further experimental work on the behavior of the water content of the mortars are given in Table 2 and shown

TABLE 2.—RATE OF DRYING OF MORTARS IN AIR.

Percentage loss of water on basis of total water lost in air drying.

Time in days.	No. 61, 1:3 cement mortar.	No. 16, 1:3 mortar, 25% lime-replacing sand.	No. 56, 1:3 mortar, 25% cement-replacing sand.	No. 16 F, 1:3 mortar, 25% flint-replacing sand.
1	36.8	24.4	39.3	29.0
2	76.7	64.9	70.7	61.4
3	87.0	77.6	78.6	77.0
4	90.1	81.6	80.6	85.9
5	93.5	85.7	84.5	88.1
6	94.5	87.9	85.8	91.1
7	95.4	90.1	87.4	92.6
13	96.9	93.1	91.5	95.6
17	98.5	97.0	95.9	98.1
30	100.0	100.0	100.0	100.0
	On basis of air dry weight of mortar.			
Per cent water lost in air drying	12.21	12.50	9.40	11.75
	On basis of weight of dry materials in mortar when mixed.			
Per cent water used in mixing	17.50	18.83	17.50	17.06
	On basis of weight of dry materials in mortar when mixed.			
Per cent water used in hydration of cement	4.05	(5.63)	7.40	(4.76)
	On basis of weight of cement.			
Per cent water used in hydration of cement	16.2	(19.2)	14.8	(17.8)

diagrammatically in Fig. 3. Mortars Nos. 61, 16 and 56 of the main series and No. 16F, containing 25 per cent ground flint rock-replacing sand, were allowed to dry in air in the laboratory in a place protected from air currents and weighed at different times for a period of thirty days. The percentage loss of water for each period of time was calculated in terms of the total water loss in air drying. The flint rock was ground to pass a 200-mesh sieve.

As Fig. 3 shows, there was not a great deal of difference in the rate of drying of the mortars. A certain amount of credit must, of course, be given to the finer-sized materials whose use caused a small decrease in the rate of drying. Of these fine materials, hydrated lime, cement, and flint had approximately the same power of decreasing the rate of drying during a critical period of the life of the mortar (0 to 7 days after molding) when the structure of the mortar is being greatly affected by the colloidal developments of the cement.

As shown in Table 2 the percentage of water apparently used in hydration of the cement is greater in mortars Nos. 16 and 16F, containing lime and flint, respectively, than in No. 61, a 1 : 3 cement mortar. This indicates that the lime and flint either aided in hydration of the cement or that they themselves retained some water. The amount of water used in hydration of cement was calculated by the use of the following approximate formula:

$$W = \frac{B - A}{100 + A} \cdot 100$$

Where

W = percentage of water on basis of weight of dry materials in mortar when mixed.

A = percentage of water lost in air drying on basis of air dry weight of mortar.

B = percentage of water used in mixing on basis of weight of dry materials in mortar when mixed.

Discussions often appear in technical and trade journals stating that the addition of small amounts of hydrated lime to cement mortars or concretes increases strength. In such discussions

no reference is made to the effect of the addition of like amounts of cement to cement mortars.

The present series of mortars was not planned on the basis of addition of lime to the mortars. However, calculation will show that the addition of lime by weight of cement amounts to approximately the same as replacement of sand by lime, and the latter method is used in the present investigation.

In Fig. 5 is shown diagrammatically the effect upon strength caused by replacing sand by lime or by cement, in the case of water storage mortars. The curves were constructed partly by means of data given in Table 1 and partly by use of inter-

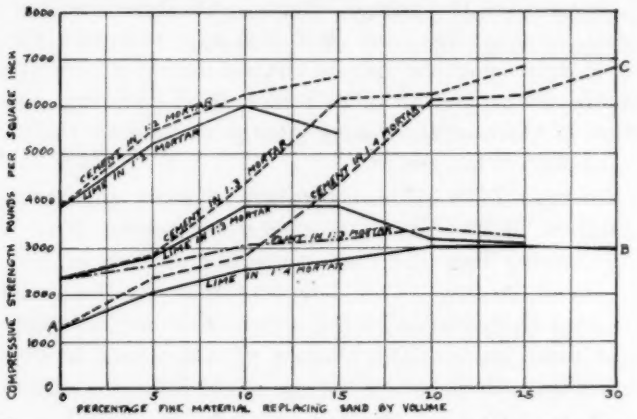


FIG. 5.—Effect of replacing sand by fine materials. Mortars stored 28 days in water. Proportions by volume.

polated values from Fig. 4. For example, the values for curves AB and AC in Fig. 5 are found at the proper points represented upon the lines AB and AC in Fig. 4. The line AB in Fig. 5 shows the increase in strength caused by replacement of sand by lime in a 1 : 4 mortar. The line AC shows the corresponding results when sand is replaced by cement, strength being higher in all cases. Similar results are found for the 1 : 3 and 1 : 2 mortars.

From these data the lime advocate will conclude that hydrated lime increases the strength of cement mortars; the cement advocate that cement increases the strength of cement mortars; the impartial observer that addition of hydrated lime increases

the strength of cement mortars but that the addition of like amounts of cement increases the strength much more.

In order to determine the effect of some fine material other than cement or lime, a number of mortars were made containing ground flint rock, passing a 200-mesh sieve. The compressive strength of these mortars was determined at the age of 28 days.

The results are given in Table 3 and those for water storage specimens are shown diagrammatically in Fig. 5. It is seen that the mortars containing hydrated lime were stronger than those

TABLE 3.—COMPRESSIVE STRENGTH OF MORTARS CONTAINING FINELY GROUND FLINT ROCK.

No.	Composition by bulk volume.				Compressive strength, pounds per sq. in. Air storage 28 days.			
					Flint.		Lime.	
	Sand.	Cement.	Flint or lime.	Water.	Air storage.	Water storage.	Air storage.	Water storage.
61	75	25	0	26.9	1225	2370	1225	2370
50	70	25	5	26.4	1645	2665	2110	2800
40	65	25	10	26.1	1925	3085	2540	3910
31	60	25	15	25.7	1935	3190	3110	3885
23	55	25	20	26.1	2265	3460	2925	3145
16	50	25	25	25.6	2215	3260	2580	3070

containing flint in all cases in air storage, and in all but two instances in water storage. The most probable reason for this behavior is that the hydrated lime is of smaller size of grain than the flint rock powder. The former is produced by slaking quicklime—giving an extremely fine powder. The latter is ground in ball mills about eight hours and could not be expected to be as fine as the hydrated lime.

Porosity.

Porosity is defined as the percentage of pore space in terms of the volume of the mortar. Porosity was determined as described under "Methods" and calculated by Purdy's formula:

$$P = 100 \frac{W - D}{W - S}$$

Where

P = porosity.
W = Wet weight of cured mortar after immersion in water.
S = Weight of wet, cured mortar suspended in water.
D = weight of cured mortar after drying at 110° C.

The relation between porosity and compressive strength is shown in Fig. 6. It is noted that the relation is quite accurate for the cement mortars but not at all accurate for the cement-lime mortars. It was attempted to obtain a closer relation by plotting strength against the product of porosity by cement-density

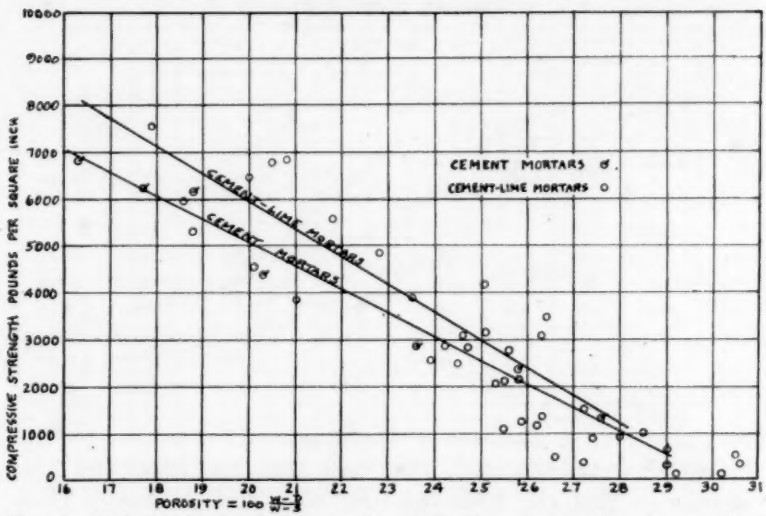


FIG. 6.—Relation between compressive strength and porosity at age of 28 days. Mortars stored in water.

(absolute volume of cement per unit volume of mortar). This method, however, proved unsuccessful. The most probable cause of these irregularities seems to be that complete saturation of the cement-lime mortars by water is not obtained by the usual method of making the test for porosity.

Water Ratio.

A function known as water ratio has recently received considerable attention in connection with the study of cement mortars

and concrete—due to the work of Abrams.[1] This function is found by dividing the volume of water by the bulk volume of cement in the mortar or concrete. The equation of the strength-water ratio curve was found to be of the form

$$S = \frac{A}{B^x}.$$

Where

S = compressive strength in pounds per square inch.

x = water ratio $= \frac{W_1}{C_b} = \frac{\text{Volume of water}}{\text{Bulk volume of cement}}$.

A and B = constants whose values depend upon the quality of the cement, the age of the specimens, and the curing conditions.

To quote from Abrams, "This equation expresses the law of

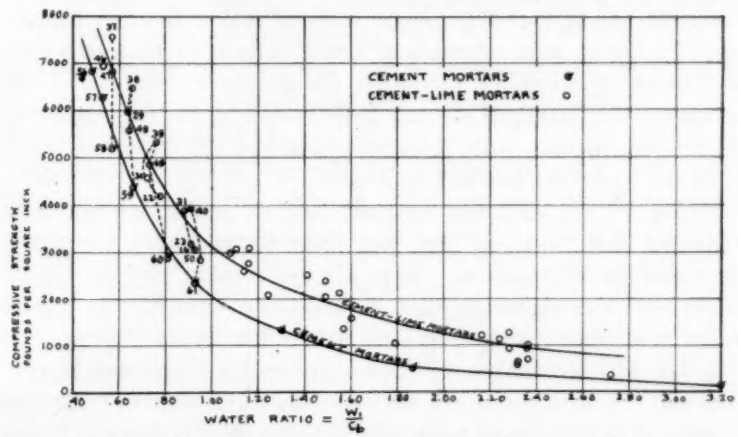


FIG. 7.—Relation between water ratio and compressive strength of mortars at age of 28 days. Stored in water.

strength of concrete so far as the proportions of materials are concerned. It is seen that for given concrete materials the strength depends on one factor only—the ratio of water to cement." The same statement applies also to mortar and neat cement.

In Fig. 7 the results for the present investigation are shown diagrammatically on the basis of water ratio. Neither of the

[1] *Engineering News-Record*, **80**, No. 18, 873 (1918).

curves shown conforms, throughout its entire course, to the equation $S = \frac{A}{B^x}$. Further mathematical treatment of these curves would serve no useful purpose since no other curves are available for mortars using the same materials and hence no comparison nor correlation could be made.

The fact that the curve for cement-lime mortars lies above that for cement mortars is not to be interpreted as meaning that the former are stronger in all cases. These curves were constructed for the purpose of subjecting the results to mathematical treatment and do not offer the proper basis of comparison, for practical purposes. The proper basis for such comparison has already been given in the discussion of the results shown in Fig. 5. For example, the builder wishes to erect a brick wall and for use in this wall has compounded a cement mortar. He wishes to increase the strength of this mortar without regard to other properties. He adds small amounts of either cement or hydrated lime (and water if necessary to obtain the proper consistency). He compares the strength of the two resulting mortars, ignoring the original mortar, since from the nature of the process it must be weaker than the two new mortars.

In Fig. 7, for example, mortars Nos. 61 and 40 are not to be compared but Nos. 40 and 59. No. 61 is only the starting point for comparison. It is a 1 : 3 cement mortar. With 10 per cent lime-replacing sand, it becomes mortar No. 40. With 10 per cent cement-replacing sand it becomes mortar No. 59.

In the article of Abrams quoted above, the discussion is very brief and it is not clear as to what variables, if any, must be controlled in order that the plotted values for strength may fall on one curve. However this may be, the fact that the plotted points for cement mortars in Fig. 7 all fall upon a uniform curve indicates that other variables were sufficiently controlled in the present investigation.

For cement-lime mortars, the water ratio method of correlation is not as accurate as could be desired. For example, in Fig. 7 certain groups of mortars have practically the same water ratio and the same volume percentage of cement but widely different strengths. Such groups are indicated by the dotted lines joining the points involved. For example, in the group containing mortar

No. 59 the strength rises to a maximum with mortar No. 38, then decreases to that of mortar No. 29, with constant increase in amount of lime. Evidently the lime should be included in a ratio or function to be used for correlation with strength in order to afford a more accurate relation.

Density of the Mortar.

Density of the mortar is defined as the absolute volume of total solids per unit volume of mortar and is calculated by the use of the following formula:

$$D = \left(\frac{S}{s} + \frac{C}{c} + \frac{L}{l}\right)\frac{R}{V}$$

Where

D = density.

S, C, and L = weights of sand, cement, and lime, respectively, weighed out for mixing.

s, c, and l = apparent specific gravities of the sand, cement, and lime, respectively.

R = weight of material in the mold divided by the total weight of materials mixed, including water.

V = volume of mold.

In Fig. 8 is shown the relation between strength and density for certain groups of mortars. Mortars represented by points

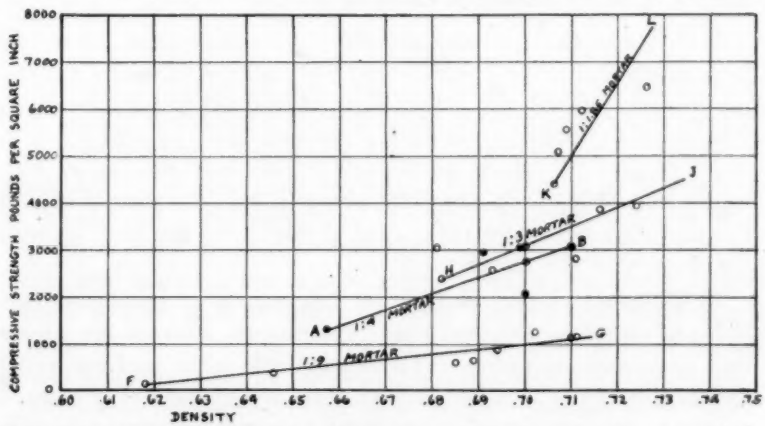


FIG. 8.—Relation between density and compressive strength of mortars stored in water 28 days.

along the line FG may be found represented upon the line FG in the triaxial diagram of Fig. 4; likewise, for the lines AB, HJ and KL. Each of these lines represents the effect of replacing sand by lime in a cement mortar. It is noted that for all the mortars, strength increases with increase of density. The point of highest strength on each of the lines corresponds to a point upon the line RR in Fig. 4 which is drawn through points of highest strength on lines parallel to FG. This means that hydrated lime acts as a void filler and increases density and strength. The maximum effect is observed at some definite amount of lime as shown by line RR in the triaxial diagram of Fig. 4.

It is desirable to represent the relation between strength and density as a continuous function. This has been done as shown in Fig. 9 where strength has been plotted against the cement-density product CD. In this product, C is the absolute volume of cement per unit volume of mortar and D is the density, as defined above. This seems to be the most accurate representation of the results. The curves of Fig. 8 show that the rate of increase of strength with density increases with the amount of cement and the next step is naturally to devise a function involving both density and amount of cement. The principles involved have been known for some time—having been stated by Feret[1] in connection with his studies of mortars.

It is noted that certain irregularities found, when the water ratio method of representation was used, do not appear when the results are plotted upon the basis of cement-density product. For example, points representing mortars Nos. 37 and 47, also Nos. 38 and 48, which lie directly above one another in Fig. 7, are well distributed along the curve in Fig. 9. This is due to the fact that the water ratio method does not take into account the density of the mortars.

In all three of the methods of representation employed (see Figs. 6, 7 and 9) the curve for cement-lime mortars lies above that for cement mortars. This fact is liable to be misinterpreted as meaning that all cement-lime mortars are stronger than cement mortars. No matter what theoretical or mathematical means is

[1] *Bull. soc. d'encour. l'ind. nat.*, **2**, 1604 (1897).

used to determine the rate of change of strength of mortars, the means used to compare the relative value of cement and hydrated lime in the mortars will be practical and will not be upon the same

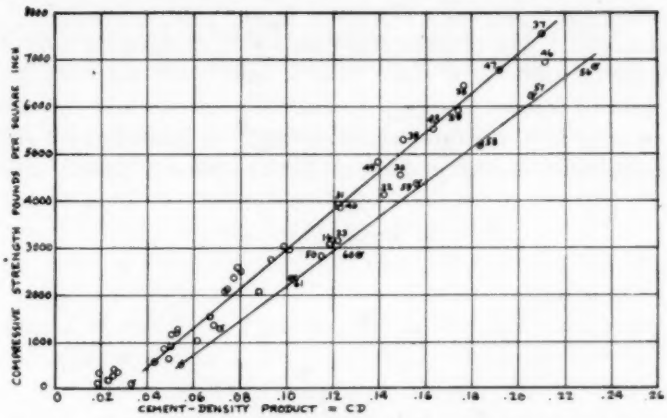


FIG. 9.—Relation between cement-density product and compressive strength of mortars stored in water at age of 28 days.

basis as the theoretical method. The practical basis for comparison has already been shown to be the percentage of cement or lime added to the mortar—the consistency being alike for all the mortars.

Conclusions.

In this investigation only one kind of lime, cement, or sand was used. Hence, the results cannot be given as much weight as would be given the averages of many tests using many different materials. They do give, however, an indication of the nature of the changes to be expected in strength of cement-lime mortars, due to change in proportions of the materials. It should be noted also that only one consistency was employed and the results would be different in degree if other consistencies were used. This would not, however, change the general relations since change in consistency would be accounted for by change in density.

Hydrated lime added to portland cement mortars in moderate amounts causes an increase of strength due to increase of density. Like amounts of cement added to the same mortars cause equal

or greater increases in strength. This is believed to be the proper and practical means of comparison which should be used in preference to any complex theoretical method. This is entirely aside from the other qualities produced in mortars by the use of hydrated lime. The present study has been of strength only.

Porosity and water ratio, which bear close relations to the strength of cement mortars, do not define accurately the relation for cement-lime mortars whose strength is governed by density and amount of cement as expressed by the cement-density product.

FUSIBILITY OF GRAPHITE ASH AND ITS INFLUENCE ON THE REFRACTORINESS OF BOND CLAY.[1]

By M. C. Booze.

The ash content of graphites used in the manufacture of graphite crucibles is considered to be detrimental both because it lowers the carbon content and because, upon ignition of the carbon, it exerts a fluxing action upon the body.

The various crucible graphites vary considerably in the per cent of ash which they contain. The Ceylon variety is probably the purest of the crucible grades, the lump containing from 2 to 15 per cent of ash and the chip from 5 to 30 per cent. The domestic graphites contain from 10 to 15 per cent of ash according to the process of milling and the specifications of the user. The average ash content of graphites used in the manufacture of crucibles is probably between 10 and 15 per cent. The ash is minutely associated with the graphite and of course can exert no fluxing action upon the body until the carbon is burned out. In a crucible, therefore, the fluxing action, if there be any, begins on the surface of the crucible, where oxidation first takes place, and proceeds inward only as fast as the ash is formed. The production of a dense skin on the crucible, which would accompany the softening of the clay and ash mixture, would retard the further penetration of gases and the combustion of the graphite so that the fluxing action of the ash would be materially retarded.

Laboratory Tests.

In the investigation, the softening points of graphite ashes and of ash and clay mixtures were determined in order to learn the extreme effect of the ash in lowering the refractoriness of graphite crucibles. The various graphites, which had been previously collected for experimental work on crucibles, were sampled by quartering down to about 200 grams. Each sample was then

[1] By permission of the Director, U. S. Bureau of Mines.

heated to 900° C in an electric furnace and held under a gentle current of air until all of the carbon had been burned out. Part of the ash so obtained was then mixed with dextrin and molded into cones of the same size and shape as the Orton standard cones. Other cones were made by mixing the ash with Mississippi bond clay in the ratio of 12 parts ash to 88 parts clay, or about the same proportion that the average crucible would show upon ignition of the graphite. The softening points of the cones were then determined against standard cones in a gas-fired pot furnace. The softening point of the clay used was determined in the same manner. The results are given in the table on the following page.

As a rule the ash from the Alabama graphite was more refractory than any of the others. The Ceylon and Canadian graphites gave ashes which were relatively quite fusible. The ash from the Pennsylvania graphite also had a low softening point.

The mixtures of clay and ash did not show the variation in softening points that might be expected from the results with the ashes alone. With the exception of three of the mixtures, a variation of only three cones was noted. The mixtures containing the ash from Alabama graphite show the highest softening points while the mixture containing ash from Canadian graphite gave the lowest softening point. The ash from Ceylon graphite, while showing a low softening point itself, gave a high softening point when mixed with clay. There appears to be little relation between the softening point of the ash and the softening point of the clay and ash mixtures.

None of the mixtures and only three of the ashes show softening points low enough to be effective at brass melting temperatures. Fourteen of the graphites gave ashes which would soften at steel melting temperatures while eight did not. Nine of the clay-ash mixtures softened at points corresponding to the highest temperatures used in crucible steel melting, three were low enough to be effective at the average temperatures used, and ten were above maximum temperature—assuming that cone 26 corresponds to a temperature of 1600° C, as given in the latest determinations.

Materials used.	Softening point of ash (cones).	Appearance of ash.	Softening point of clay-ash mixtures (cones).	Appearance of clay-ash mixtures.
No. 1 Alabama graphite	17	Black	26	Slightly swollen
No. 1 Alabama graphite	18	Black, slightly swollen	27	Gray, badly swollen
No. 2 Alabama graphite	32	Black	29+	Gray, slightly swollen
No. 1 Alabama graphite	30	Black	29+	Gray, slightly swollen
No. 2 Alabama graphite	20	Black	27	Gray, spotted
Alabama graphite dust	30	Black	29+	Gray, swollen
Alabama graphite dust	31	Brown	29	Gray, swollen
Alabama graphite dust	31	Brown	29+	Gray, swollen
No. 2 Alabama graphite	32	Brown	28	Buff, swollen
No. 2 Alabama graphite	17	Brown	26	Gray, slightly swollen
No. 1 Alabama graphite	32	Brown	29	Gray, swollen
No. 1 Alabama graphite	18	Brown	26	Gray, slightly swollen
No. 1 Alabama graphite	23	Brown	27 1/2	Buff, swollen
No. 1 Alabama graphite	17	Brown	26	Gray, slightly swollen
No. 1 Alabama graphite	32	Brown	26	Gray, slightly swollen
No. 1 Alabama graphite	16	Black	26	Gray, slightly swollen
No. 2 New York graphite	8	Black	23	Iron spots, slightly swollen
New York graphite dust	3	Black	26	Gray, swollen
Canadian graphite, crucible grade	1	Black	17	Gray, swollen
Ceylon graphite, crucible grade	2	Black	26	Iron spots, slightly swollen
No. 1 Penna. graphite	20	Black	19	Black, swollen
Pot shell, crucible grade	9	Black, swollen	26	Gray, swollen

Softening point of Mississippi clay.....Cone 30

A degree of softening below that obtained in the clay-ash cones would undoubtedly be detrimental to a crucible, but since the clay and ash in a crucible are not so intimately blended as in the cones, the softening point of the crucible mixture may even be higher than herein registered. The clay used for this work showed a softening point of cone 30—which is somewhat low for steel crucibles. Clays of the type used for steel crucibles do not vary widely in their composition and the use of a more refractory bond clay should still further raise the softening points of the mixtures.

Conclusions.

The softening point of a graphite ash is not a true criterion of its action in a crucible body.

The tendency of graphite ash to lower the refractoriness of a crucible is not evident at brass-melting temperatures and would seldom be detrimental even in steel melting crucibles.

The ash from Alabama graphite is less effective as a flux than the ashes from the Ceylon, Canadian, Pennsylvania or New York graphites.

Bureau of Mines,
Mining Experiment Station,
Columbus, Ohio.

CLAYS FOR USE IN PAPER-MAKING.

By Ralph B. Roe.

For a great many years it has been customary to introduce a certain amount of mineral fillers or loading materials into the suspension of fibers in water which forms the basis of paper. In the conversion of this suspension of fibers into a sheet of paper, a considerable proportion of the mineral filler is lost, while the balance remains associated with the fiber in the paper sheet—contributing in no small degree to its physical characteristics.

Without knowing the effects of such an addition of loading materials, one might be inclined to consider the practice more or less reprehensible for the same reason that the introduction of fillers, loading materials, and "make weights" constitutes an adulteration in the case of many well-known articles of commerce and every-day use. Although the introduction of relatively cheap and heavy fillers actually does decrease the intrinsic value of the paper, especially since the latter is almost always sold on a basis of weight, the physical qualities imparted to the sheet really constitute the primary object in view, and it is no exaggeration to say that without fillers it would be quite impossible to manufacture a product that would give satisfactory service in some of the widest and most essential applications in which paper is used.

A sheet of machine-made paper is essentially an interlaced structure of individual fibers and as such will show not only an uneven surface but it will also be apparent that owing to its structure there will be innumerable interstices between the individual fibers comprising the sheet. When it is considered that for printing purposes a physically even and close texture is a prime requisite, it becomes evident that a sheet of paper with these qualities is not perfectly adapted for fine printing work. The introduction of a filler acts toward filling the interstices or voids in the paper. At the same time the sheet becomes softer and more pliable and, the surface being smoother, is capable of receiving a higher mechanical finish in the course of manufacture.

Even more important is the tremendous effect on opacity. A thin sheet of paper of a given fibrous composition and thickness would be utterly useless for printing purposes compared to the same sheet heavily loaded with a filler. The well-known thin printing papers, referred to as bible and India papers, owe their amazing opacity to the relatively high content of filler. It should be understood, however, that the desirable effects of loading are gained at the expense of strength, and it is in only those paper stocks that are so manipulated as to yield extraordinary strength that high percentages of filler can be employed without seriously affecting the wearing qualities of the paper.

In addition to incorporating mineral agents into the sheet, there is another and somewhat different field of application. This consists in applying the mineral ingredient mixed with a suitable binder to the surface of the sheet. In this way a surface is obtained which is susceptible of receiving a very high finish. This product, known as coated paper, is used in high-grade printing and illustration work.

The number of mineral ingredients used for filling and coating papers is comparatively restricted. For filling purposes may be mentioned clay, sulphate of lime (known in commerce under various names such as pearl hardening, crown filler, terra alba, gypsum, etc.), talc, asbestine or agalite, and blanc fixe, or precipitated sulphate of barium. For coating, clay, blanc fixe, and satin white are the most important. Satin white may be described essentially as a mixture of precipitated sulphate of lime and hydrate of alumina with more or less hydrate of lime.

Of all the materials in use for loading and coating purposes, clay is by far the most important—a fact which is largely due to the relatively low cost of this material. The source of the clay used in the finest grades of paper has been for many years almost exclusively confined to England. An excellent natural product, methods of production yielding a very high-grade material, and favorable shipping conditions, all operated to cause the continued use of English clay and conversely inhibited the growth and development of domestic clays for this purpose. For a number of years American clays have been exploited for paper-making purposes but with a few exceptions they were of decidedly poor

quality. Owing to war conditions, however, there has been considerable difficulty in obtaining English clay and increased attention has been directed to clay of domestic origin. Before making any comments on the relative merits of English and American clays, some mention should be made of those characteristics by which the quality of a clay is rated. The most important points to be considered are: (1) Color; (2) Grit; (3) Retention.

The value of any clay for either filling or coating purposes is largely affected by the color. There is a decided tendency toward the yellow in natural colored paper and it is the universal practice to correct this yellow cast by the addition of a small amount of a blue pigment or dye. Since the amount of clay contained in the more common grades of printing papers will run as high as 20 per cent, it is obvious that the color of the clay determines in no small degree the color of the sheet. While a high white is an important consideration in clays used for fillers, it is especially to be desired in clays used for coating. In the latter case all of the clay lies in a layer or coating on the surface of the sheet and the color of the paper is entirely determined by the color of the clay.

The color of clay, insofar as it concerns paper-making practice, is judged entirely by arbitrary standards. For coating and high-grade printing papers the highest possible white is desired, whereas for cheap printing papers, a clay with a decided gray or yellow cast may be perfectly satisfactory.

To compare the color of any standard sample and an unknown specimen, a small amount of each is reduced to a fine powder and the two are then dried for a short time to ensure approximately the same moisture content. A portion of each is placed on a glass plate or sheet of white paper in such a way that the two samples lie side by side. With a paper or spatula the two samples are flattened out carefully so that they present a smooth, even surface with a common line of demarcation between the samples. The slightest difference in color shows up plainly by contrast.

The second desirable quality in a clay concerns its content of grit. By grit is included those particles of a sandy or siliceous nature together with those occurring in flakes or leaflets and micaceous in appearance. Siliceous grit is particularly objection-

able for the reason that it causes an excessive amount of wear on the fine wire of the paper machine. It moreover is likely to cause breaks in the paper during the progress of the sheet from the wet-end to the dry-end of the paper machine, and finally it manifests itself unmistakably in the finished sheet, by pin-holes, specks, etc. Micaceous grit is objectionable, largely because of its showing up as shining specks in the paper. These specks are very likely to cause trouble in printing—due to the particles picking off.

The estimation of grit is easily and quickly made by weighing a definite quantity of the sample (10 grams or more), transferring into a beaker or cup, and adding water. As soon as the clay has disintegrated, the contents of the beaker are transferred to a 200-mesh screen and the residue on the screen worked carefully with the finger while a small stream of water plays on the sample until nothing remains that may be washed through the screen. The residue is then dried, transferred to a paper, and weighed. It is expressed as a percentage of the original sample. The best clays do not contain more than 0.20 per cent of grit and there are many samples showing less than 0.10 per cent.

The retention of a clay is a term used to express the percentage ratio between the amount of filler used and the amount retained in the paper. The amount of filler retained is the sum of a number of physical conditions including certain characteristics in the clay itself together with the nature and treatment of the fibrous material composing the paper. Since the clay not retained is usually lost, the percentage retained has an appreciable bearing on the cost of production.

There is no satisfactory method for directly estimating the retention of a clay, and the necessary data is usually accumulated by actual test in the paper mill. Although there are no direct methods for estimating retention, certain indirect methods have been suggested which furnish comparative data on the retention of clays. The principle involved is graduated levigation or elutriation under carefully controlled conditions.

Attention was directed earlier in this paper to the recent tendency to develop American clays for use in paper-making. For many years there was a distinct prejudice in most quarters against local clays, it being claimed that the English article is of better

color, contains less grit, and possesses to a higher degree those qualities which are peculiarly essential in a coating clay. As far as color is concerned, domestic clays tend to a yellow tone whereas the imported article is more of a blue-white. It is a fact, however, that some of the higher grades of English clay are artificially colored with a blue coal-tar dye, which undoubtedly accounts for the superior color. In some cases ultramarine has been used for the purpose. This pigment is unstable under conditions which might easily obtain in paper-making, in which case the color imparted would fade. While the average English clay is better in color than the average American clay, some of the domestic clays now on the market are of good color and are admitted in most quarters to be quite satisfactory for filling purposes.

The prejudice against domestic clays is to a large extent founded on the excessive amount of grit which was shown in the earlier grades. The evil effect of grit in clay is easily demonstrated and any feeling engendered against a clay on this ground is quite justified. In the past few years, however, some of the domestic clays have been so far improved in this respect that they do not suffer by comparison with the imported product. It must be admitted that the reputation acquired in the past for excessive grit has been difficult to overcome.

For coating purposes, the view seems to be quite universally held that domestic clay does not fulfill the requirements of the trade. Excepting color, which must be high, there are certain rather obscure characteristics which render the English clay peculiarly well fitted for the purpose. It is probable that these desirable qualities are intimately connected with the plasticity. Although considerable research work has been carried out on the subject of paper-making clays, the matter would seem to offer great possibilities for further work with especial reference to the coating problem.

In conclusion, it is not unduly optimistic to hope that even as domestic clays have been increasingly used for fillers, continued and thorough research will prove that the more exacting requirements of the coated paper manufacturer are not inherently impossible of being met by our American clays.

ARTHUR D. LITTLE, INC.,
CAMBRIDGE, MASS.,
January 30, 1919.

AMERICAN CERAMIC SOCIETY.

Acquisition of New Members during January, 1919.

Associate.

Allcock, F. T., American Encaustic Tiling Co., Zanesville, Ohio.
Anderson, F. E., 905 Commonwealth Bldg., Pittsburgh, Pa.
Becket Frederick M., Union Carbide Co., Niagara Falls, N. Y.
Biachford, H. L., The Fairite Co., 669 W. Ohio St., Chicago, Ill.
Brinkman, S. G., Fords, N. J.
Brown, Lawrence H., 1835 Indianola Ave., Columbus, Ohio.
Burchfiel, B. M., Mellon Institute, Pittsburgh, Pa.
Callahan, H. D., 434 E. Long St., Columbus, Ohio.
Carling, J. P., China Products Co., Zanesville, Ohio.
Chang, C. Y., 228 W. Lane Ave., Columbus, Ohio.
Davis, Harry E., 396 Stoddart Ave., Columbus, Ohio.
Douda, Henry W., 11 E. 18th Ave., Columbus, Ohio.
Evans, A. W., Zanesville, Ohio.
Faulkner, Karl B., Corning Glass Works, Corning, N. Y.
Hepplewhite, J. Wilson, 1835 Indianola Ave., Columbus, Ohio.
Koos, E. Kenneth, 1210 Dennison Ave., Columbus, Ohio.
Kraner, Hobart M., 61 Welch Ave., Columbus, Ohio.
Kreger, John M., Monument Pottery Co., Trenton, N. J.
Laird, Charles, 16 Fifteenth Ave., Columbus, Ohio.
Liang, Ching-Hsia, 174 W. Lane Ave., Columbus, Ohio.
Long, Russell N., 1932 Waldeck Ave., Columbus, Ohio.
Oakley, Walter W., 32 E. 2nd St., Corning, N. Y.
Odelberg, A. W., Gustafsberg, Stockholm, Sweden.
Parr, John R., 224 Sinclair Place, Westfield, N. J.
Reeb, H. E., 269 S. 18th St., Columbus, Ohio.
Smith, H. Dan, Smith-Phillips China Co., East Liverpool, Ohio.
Taylor, Wm. C., Corning Glass Works, Corning, N. Y.
Trace, A. R., Haydenville, Ohio.
Twining, F. E., The Twining Laboratories, Fresno, California.
Van Cleave, A. A., Odell St., and Watson Road, St. Louis, Mo.
Winkleman, E. J., 315 Union Arcade Bldg., Pittsburgh, Pa.
Wong, Y. Y., 56 W. Frambes Ave., Columbus, Ohio.

Contributing.

Consolidated Window Glass Co., Bradford, Pa.
Edward Ford Plate Glass Co., Rossford, Ohio.
Jefferson Glass Co., Follansbee, W. Va.
Johnston Brokerage Co., First National Bank Bldg., Pittsburgh, Pa.

$6,831.35

The Value of Fuel Saved in One Year.

¶ Actual records were kept for 365 days of the burning of 9-inch, high-grade, refractory brick in one continuous tunnel kiln and in seven 30-foot round kilns, during which time 5,110,000 brick were burned in the tunnel kiln as against 5,040,000 in the seven round kilns.

¶ But this isn't all—the actual labor saving amounted to $5,808.00. Taking into consideration the necessary items of depreciation, interest on plant, maintenance and repairs, the average yearly cost for burning 1,000 brick in the continuous tunnel kiln system was $2.95 as against $6.20 in the round kilns.

¶ If you are really interested in the greater efficiency of burning, you will let us tell you more about the actual accomplishments of

The Didier-March Continuous Railroad Tunnel Kiln

Didier-March Company

GEO. A. BALZ *Gen'l Mgr.* **Perth Amboy, New Jersey** LOUIS A. WITTE *Chief Engineer*

Contractors *Manufacturers of Refractories* *Engineers*

THINK!

What would it mean to your business if you could install an automatic dryer for green molded or formed ware? A dryer that is really automatic and positive—that produces a uniformly dried piece in the same drying time, winter or summer, and dries so scientifically that both the cost and the time of drying are materially reduced.

What would that mean to you, Mr. Manufacturer—in terms of improved product, increased production, standardized manufacturing routine?

Tell us what your product is and we'll tell you how much you can save and improve by depending upon a guaranteed Carrier Dryer instead of depending upon the weather or the older types of dryers. ***Write right now.***

Carrier Engineering Corporation

39 Cortlandt Street, New York

Boston **Philadelphia** **Buffalo** **Chicago**

Carrier AIR CONDITIONING AND DRYING EQUIPMENT

"EVERY DAY A *GOOD* DAY"

The Mandle Clay Mining Company

ESTABLISHED 40 YEARS *OFFICE: ST. LOUIS, MO*

Mines Located in Tennessee and Kentucky

Our materials STANDARD for manufacturing every line of product in which are used BALL, WAD, SAGGER, and HIGH GRADE REFRACTORY BOND CLAYS.

For Pottery and Porcelain of all kinds
For Glass Industries and Crucible Manufacturers

Quality *Uniformity* *Experience*

Edgar QUALITY *Clays*

REALLY washed—Highest percentage clay substance

Brands	*Produced by*
Edgar Florida Kaolin	*Edgar Plastic Kaolin Co.*
Edgar Georgia Paper Clay and Kaolin	*Edgar Brothers Co.*
Lake County Florida Clay	*Lake County Clay Co.*

One Management—Office, Metuchen, N. J.

Zwermann *Twin* Tunnel Kiln

Note Its Chief Advantages:—

First:—The first cost of this kiln compared with a single tunnel of the same capacity is considerably lower. It requires less brick, one-half of the buck stays, less space, and no side or return track.

Second:—This twin tunnel kiln allows a greater utilization of the fuel than a single tunnel kiln, as the heat from cooling ware is used for water-smoking the incoming ware.

Third:—This kiln allows an absolute and positive control of the firing zone, and in the firing zone a reducing or oxidizing condition can be maintained at will.

Fourth:—The cooling of the ware as well as the water-smoking and pre-heating in this kiln are absolutely automatic. It is impossible to get the receiving end of the tunnel too hot.

Fifth:—This kiln will save about 50% on labor and from 65% to 75% on fuel as compared with periodic kilns. Burning time is cut down by ⅓ to ½. Where saggers are used, they will last twice as long.

Carl H. Zwermann **Newark, O.**

Over 80%

of all pyrometer-equipped ceramic plants use Browns. In small plants and large plants, at Pennsylvania, American Encaustic and Metropolitan, Brown Pyrometers are helping to produce better ware and more of it—and saving fuel at the same time.

Write for complete information to

THE BROWN INSTRUMENT CO.
PHILADELPHIA, PA.
New York. Pittsburgh. Detroit. Chicago. St. Louis.

Brown Pyrometers

JOURNAL OF THE AMERICAN CERAMIC SOCIETY

The only technical periodical reaching all ***branches*** *of the great ceramic industry, (brick, tile, terra cotta, pottery, porcelain, sanitary ware, refractories, glass pots, sewer pipe, tiles, cements, glass, etc., etc.)*

RATES

1 page	$40.00	per insertion	
1/2 "	25.00	"	"
1/4 "	15.00	"	"
1/8 "	10.00	"	"

20% discount for 12 continuous insertions

For further particulars address

COMMITTEE ON PUBLICATIONS,
L. E. Barringer, Chairman,
Schenectady, N. Y.

American Ceramic Society, 211 Church St., Easton, Pa.

Make Your Allotment of Fuel Produce More Output.

SIL-O-CEL

TRADE MARK REGISTERED U.S. PATENT OFFICE

MADE FROM CELITE

Insulation insures a greater producing capacity from your kilns because it prevents heat loss.

The enormous amount of heat which is lost through the setting of uninsulated kilns is retained in the kiln by Sil-O-Cel Insulation and made productive.

Sil-O-Cel Insulation insures better temperature control, more uniform interior temperatures and less waste due to over- and under-burned pieces.

Write for Bulletin B-5

Write for detailed information and blue prints.

CELITE PRODUCTS COMPANY.

New York Chicago Pittsburgh Los Angeles San Francisco

Alundum NORTON **Crystolon**

AND

The modern abrasives which make up the

NORTON GRINDING WHEELS

have played an important part in the evolution of grinding.

Improved methods of wheel manufacture, co-operating with modern research and experimental laboratories, have helped develop a Norton Grinding Wheel of the right grain and grade for every grinding job.

Our experience is at your service in selecting a wheel or solving a difficult grinding problem.

NORTON COMPANY

WORCESTER, MASS.

Alundum Plant: Niagara Falls, N. Y.
Crystolon Plant: Chippawa, Canada

New York Store: 151 Chambers Street
Chicago Store: 11 No. Jefferson St.

(600)

THE ROESSLER & HASSLACHER CHEMICAL COMPANY.

NEW YORK

"America's Leading Ceramic Material House"

Manufacturers and Distributors
of the well-known

RHCCO
Al

Ceramic Chemicals

Distinctive — Constantly Uniform
Most Economical — Always Reliable

The BETTER GRADE Products

that immediately relieve your mind of the annoying question ***QUALITY***

Branches

Chicago
Boston
New Orleans
Cleveland
Philadelphia
Cincinnati
Kansas City
San Francisco

The Leeds & Northrup Optical Pyrometer in Use

Temperatures at Sight

The temperatures of incandescent or glowing bodies are read with great accuracy by inexperienced operators using the Leeds & Northrup Optical Pyrometer.

The operator sights at the hot object through a small telescope held in the hand.

The filament of a small tungsten lamp is seen against the background of the hot object. The operator regulates the current through the lamp by turning a rheostat in the battery box until the filament merges with or disappears against the background.

The current flowing through the lamp is read on the milliammeter mounted on the battery box. This current indicates the temperature of the hot object.

A large surface to sight upon is not required, nor does the distance from the hot object matter.

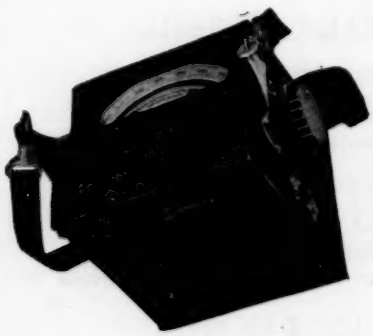
The comparison is made in light of one color only, therefore, the ability to match colors and color blindness have no effect upon the reading.

The adjustment of current by the operator is unconsciously one of great precision, as the light varies much more rapidly than the temperature and the eye is very sensitive in comparing the brightness of surfaces superimposed, one upon the other.

Different observers agree within 3° C. when using the Leeds & Northrup Optical Pyrometer.

State conditions of use, and full particulars, including descriptive Bulletin, will be supplied.

The Leeds & Northrup Optical Pyrometer



Case containing storage battery, rheostat and milliammeter for Leeds & Northrup Optical Pyrometer

THE LEEDS & NORTHRUP CO.

4901 STENTON AVE. PHILADELPHIA, PA. 21

Established 1869

SELENIUM

—POWDERED—

Crystalline

and

Amorphous

B. F. DRAKENFELD & CO., Inc.

IMPORTERS AND MANUFACTURERS OF

INDUSTRIAL CHEMICALS, OXIDES.

Vitrifiable Colors and Materials

For Pottery, Glass, China and Enameling.

PERFECTION KILNS

For Glass, China and Pottery.

DECORATORS' SUPPLIES.

Main Office: 50 MURRAY STREET, NEW YORK.

BRANCHES:

CHICAGO, ILL. *EAST LIVERPOOL, O.*

DETROIT, MICH.

"Proctor" DRYERS

For Clay Products

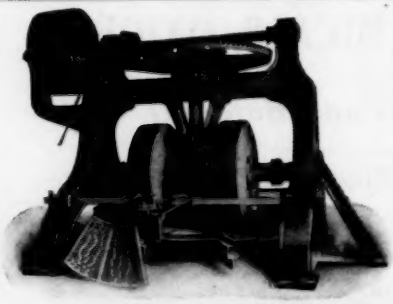
MAKE BETTER WARE AT A LOWER COST

WRITE FOR CATALOG

The Philadelphia Textile Machinery Co.

Seventh Street and Tabor Road

Philadelphia, Pa.



American Nine Foot Dry Pan

Here's one of our famous line of pans. They are built to handle a lot of clay and they do it. Nothing shoddy about this pan, that's why it makes good and works steadily without trouble. Get our pan printed matter. We surely have a pan to do your work better and with less trouble and expense than you are now doing it. Let us prove it.

The American Clay Machinery Co.
Bucyrus, O.

J. T. BRAMLETT

HIGH GRADE
PLASTIC FIRE CLAY

A Bonding Material Suitable for Crucibles, Glass Pots, Etc.
Sold Direct to Consumer

ENID, MISSISSIPPI

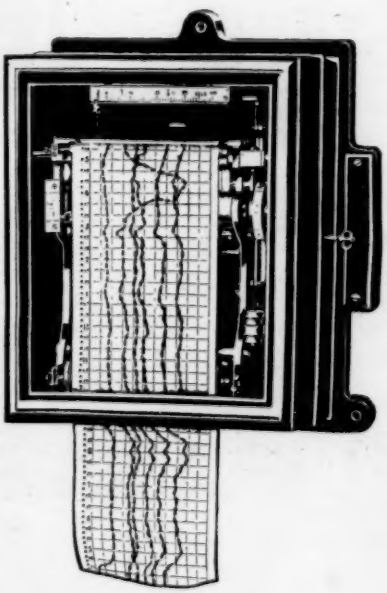
This War Will Banish, Not Only Autocracy But Also Inefficiency and Waste

You will be compelled to conserve COAL because close government supervision over all natural resources will unquestionably continue.

You will be forced to cut your use of LABOR to a minimum because it will be many years before there will again be a sufficiency of help.

On the other hand — there will come a tremendous demand for building products, and the plant manager who is far-seeing is PREPARING NOW so he will be able to turn out a MAXIMUM of good ware at a MINIMUM cost.

Engelhard Le Chatelier Pyrometers



Offer you the best possible means for meeting this situation in the way that will eliminate the "leaks" and make your PROFITS commensurate with your broader activities.

Our expert engineers know the clay field—they can point to many remarkable successes—they can tell **you** what to do to protect yourself against the common enemies — Inefficiency and Waste.

We are Ready to Serve

Charles Engelhard

30 Church St., New York, N. Y.

DURABILITY

Is the vital quality of the brick that are used in copper furnaces and open-hearth steel furnaces. And that's why the Laclede-Christy Bauxite Brick have proved so remarkably popular--they stand the test.

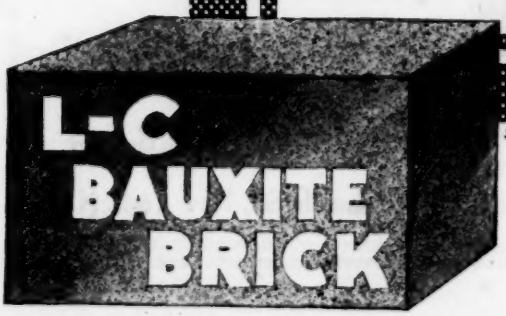
L-C Bauxite Brick are being used as a substitute for Magnesite Brick with great success--they are cheaper and in many cases have proved more durable.

You can't afford to gamble on refractories of inferior quality **now**. Shut-downs at this time are disastrous. Be on the safe side--use L-C Bauxite Brick in the walls of your furnaces. Tell us your requirements and let us quote you prices.

LACLEDE-CHRISTY

Everything in Clay Products

Railway Exchange Bldg., St. Louis, Mo.



B5

HF&G

SELENIUM

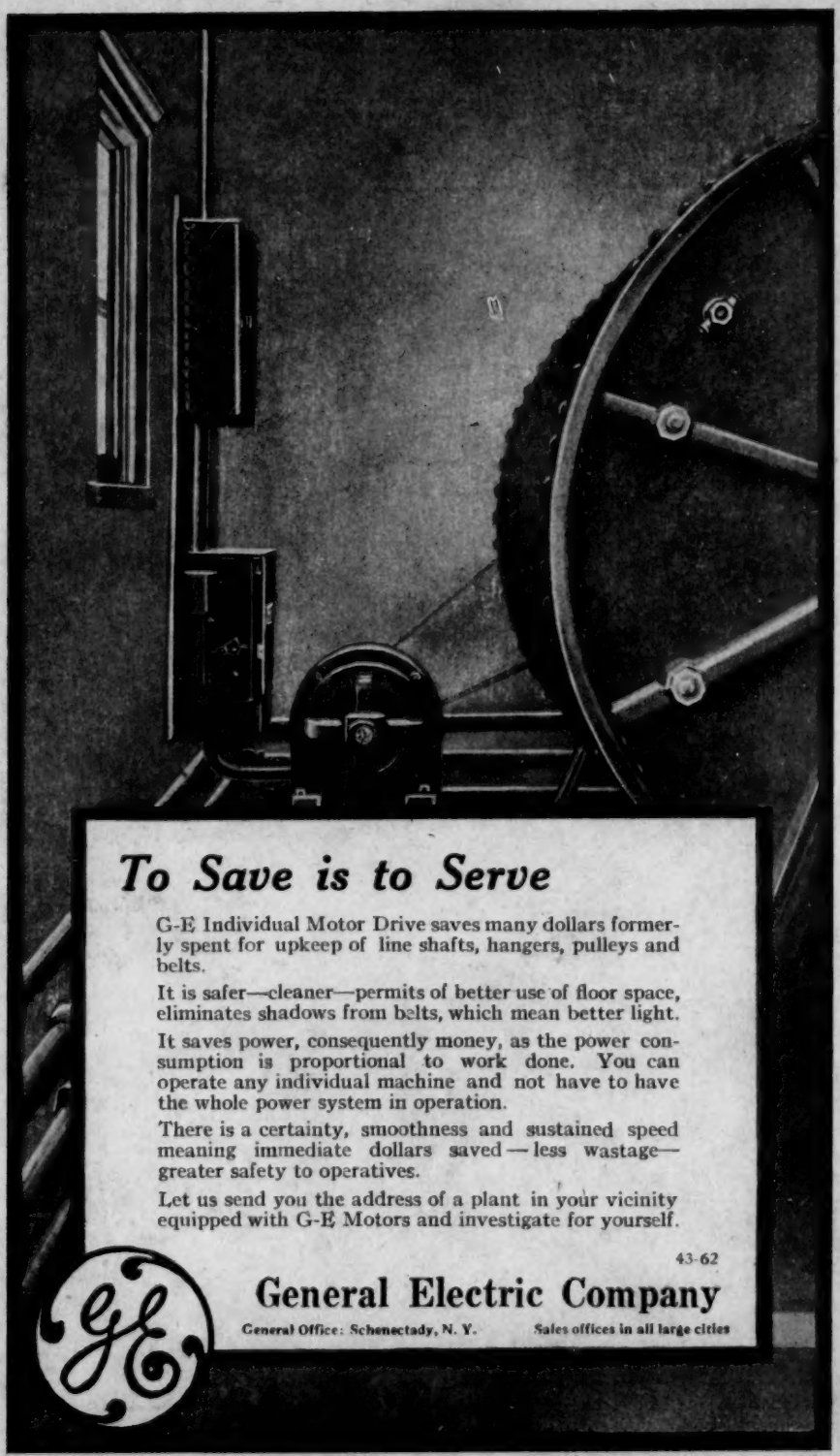
COBALT OXIDE

BLACK OXIDE MANGANESE

ANY GRADE ANY GRINDING

THE HARSHAW FULLER AND GOODWIN CO.

CLEVELAND NEW YORK PHILADELPHIA



To Save is to Serve

G-E Individual Motor Drive saves many dollars formerly spent for upkeep of line shafts, hangers, pulleys and belts.

It is safer—cleaner—permits of better use of floor space, eliminates shadows from belts, which mean better light.

It saves power, consequently money, as the power consumption is proportional to work done. You can operate any individual machine and not have to have the whole power system in operation.

There is a certainty, smoothness and sustained speed meaning immediate dollars saved — less wastage—greater safety to operatives.

Let us send you the address of a plant in your vicinity equipped with G-E Motors and investigate for yourself.

43-62

General Electric Company

General Office: Schenectady, N. Y. Sales offices in all large cities